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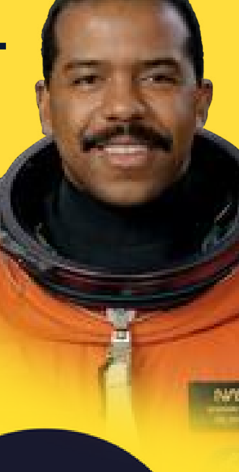

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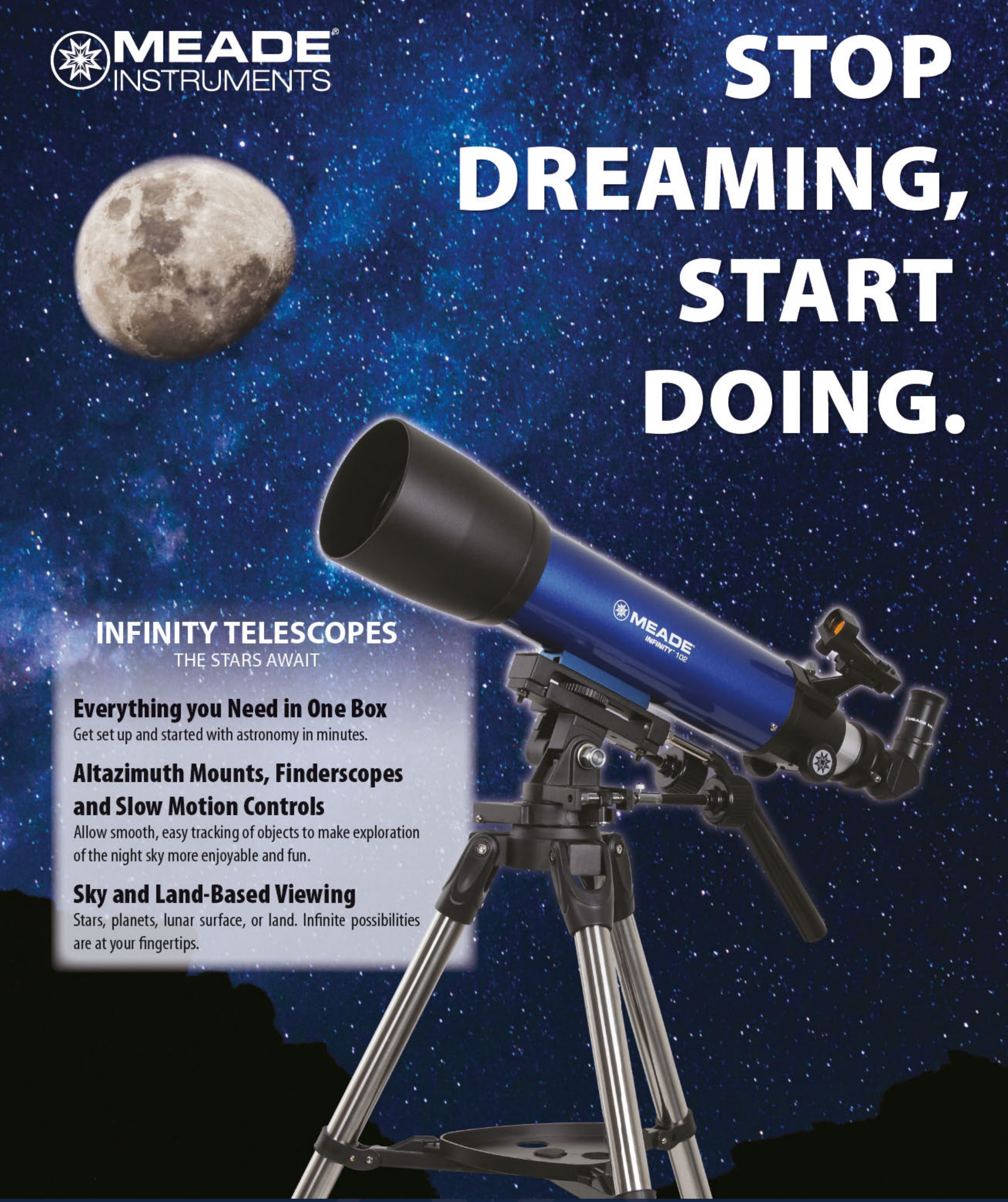

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Milky Way's burst

Are we any closer to solving the mystery of our galaxy's radio pulses? **58**

This month **All About Space** returns to the concept of dark matter, hailed as the most mysterious substance in the universe next to dark energy. There's a plethora of questions astrophysicists are posing and working to solve in order to get closer to understanding it once and for all.

What (we think!) we know about dark matter is how much comprises the cosmos and how it behaves. What we're still trying to figure out is what it's made of and where it actually came from. This issue, you'll discover that a team of astronomers at the University of Houston, Texas, and the University of Melbourne, Australia, has an idea in mind - it could have been forged by ballooning cosmic bubbles, which led to its abundance in the universe.

The team reasons that dark matter would have sprung into existence not long after the earliest period of the cosmos' formation. A time when it was a fiery soup of elementary particles, bubbling like a searing pot of liquid, which cooled as the universe expanded. The particles then grew further apart, with collisions becoming less likely as time wore on. Dark matter would have been filtered out of the bubbles of plasma, eventually taking its place in space and time. Turn to page 14 for the full report.

See you next issue - have a great Christmas!

GEMMA LAVENDER
EDITOR-IN-CHIEF

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It's eluded us for decades, but cosmic bubbles could be the answer to the most mysterious substance in the universe

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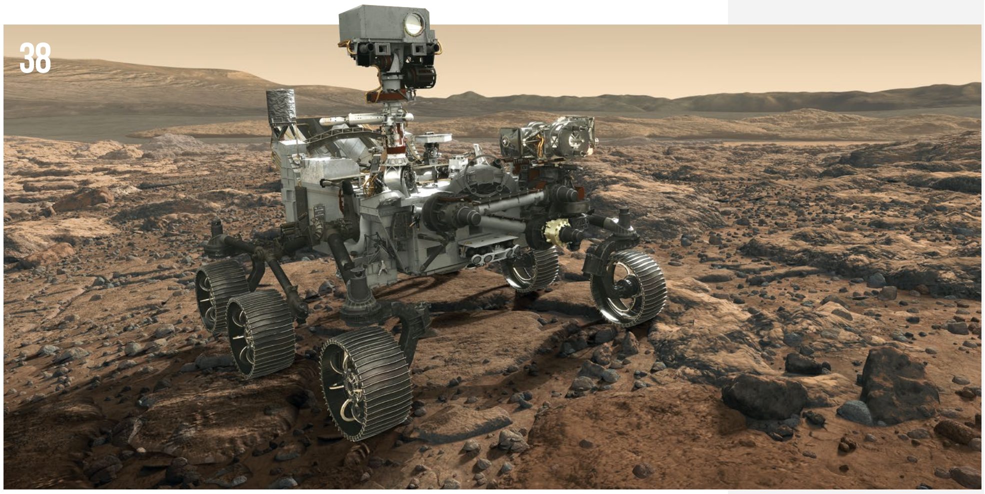

> *"I would love to go back. I would stop everything"* Bernard Harris

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Prior to its decommissioning and sudden collapse, this huge dish made many invaluable contributions

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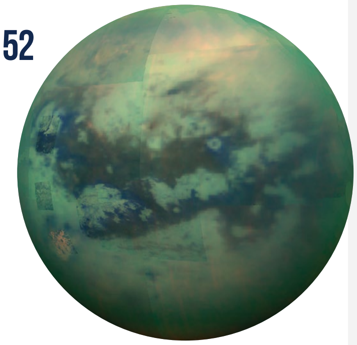

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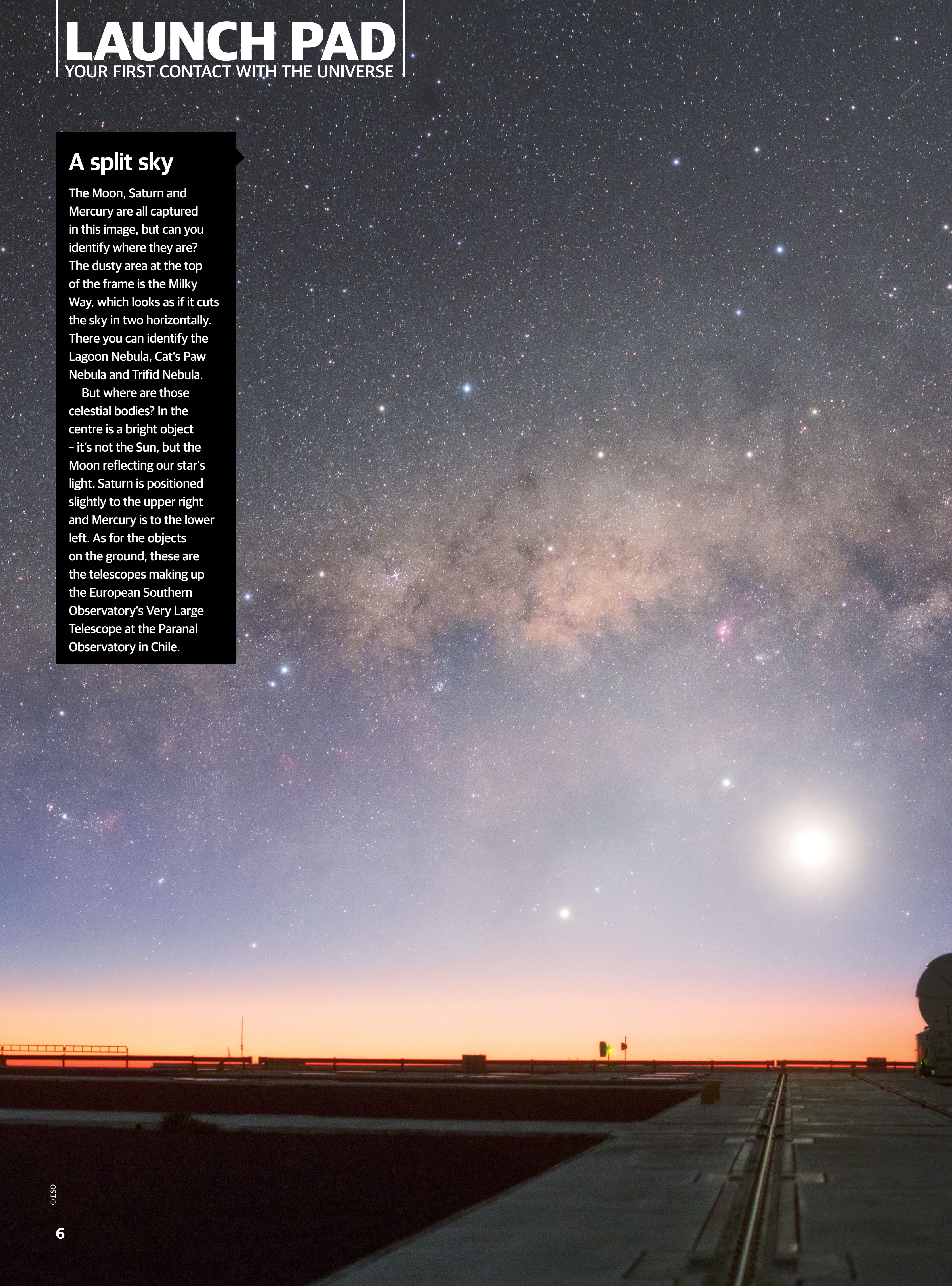

A split sky

The Moon, Saturn and Mercury are all captured in this image, but can you identify where they are? The dusty area at the top of the frame is the Milky Way, which looks as if it cuts the sky in two horizontally. There you can identify the Lagoon Nebula, Cat's Paw Nebula and Trifid Nebula.

But where are those celestial bodies? In the centre is a bright object – it's not the Sun, but the Moon reflecting our star's light. Saturn is positioned slightly to the upper right and Mercury is to the lower left. As for the objects on the ground, these are the telescopes making up the European Southern Observatory's Very Large Telescope at the Paranal Observatory in Chile.

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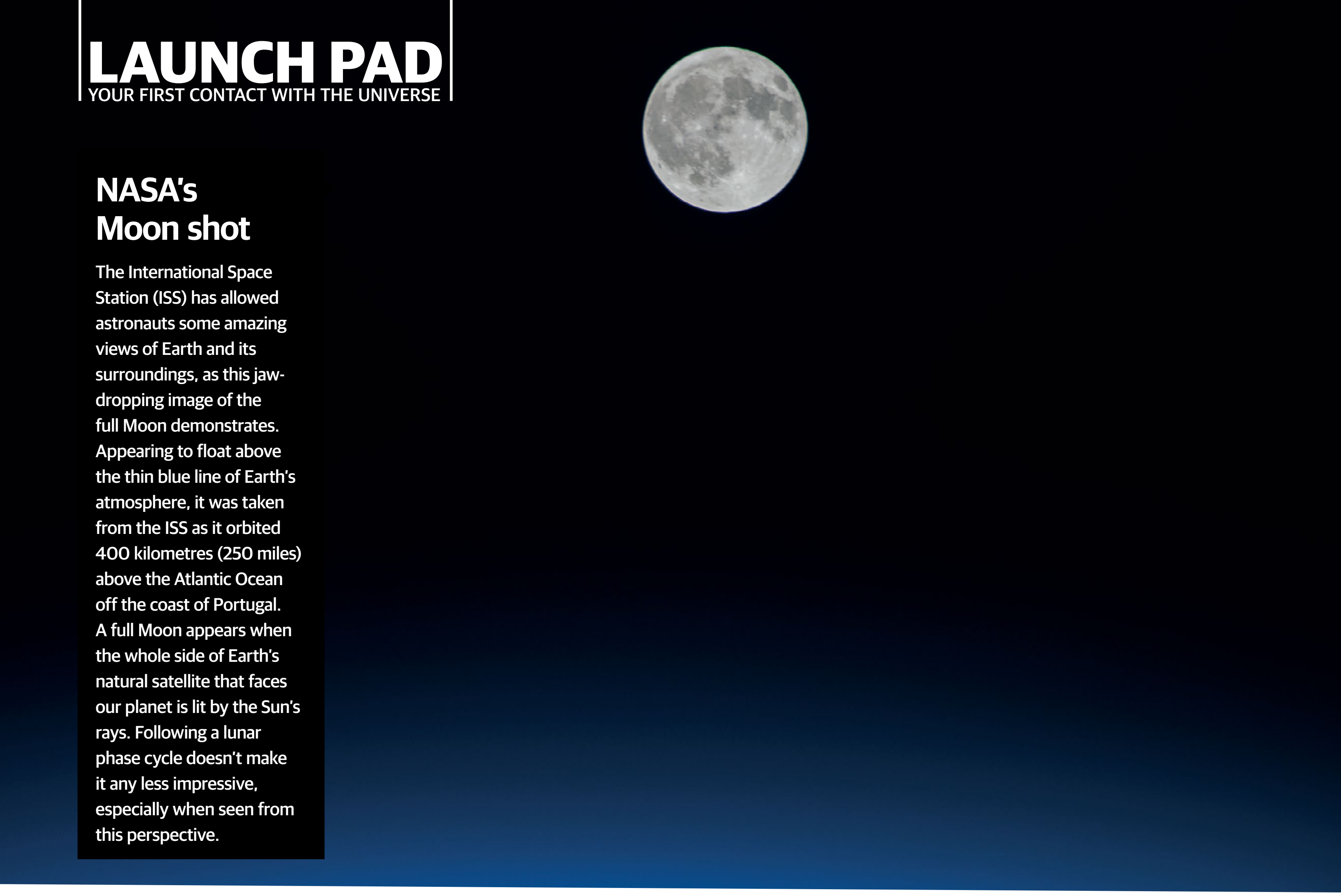
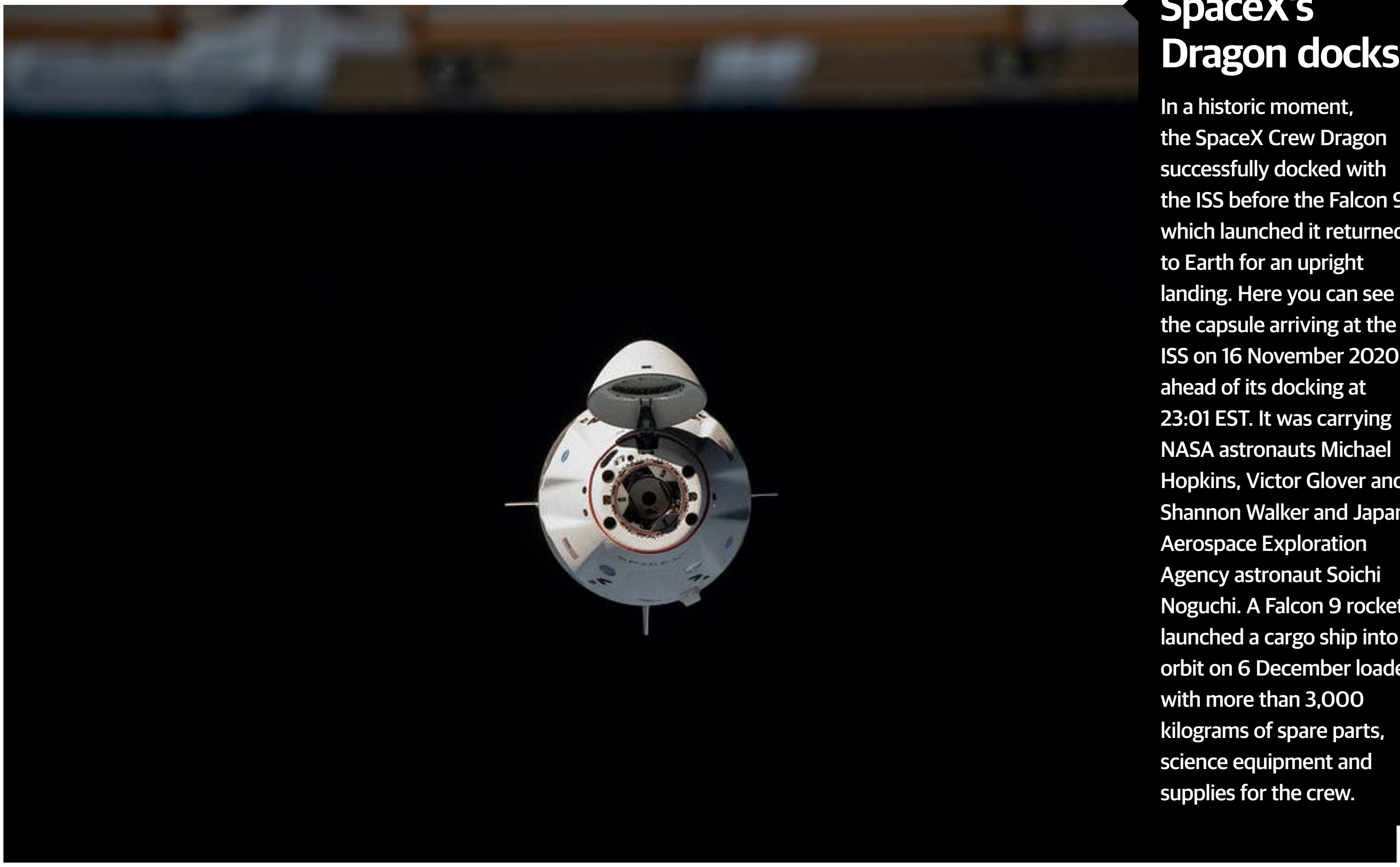


NASA's Moon shot

The International Space Station (ISS) has allowed astronauts some amazing views of Earth and its surroundings, as this jaw-dropping image of the full Moon demonstrates. Appearing to float above the thin blue line of Earth's atmosphere, it was taken from the ISS as it orbited 400 kilometres (250 miles) above the Atlantic Ocean off the coast of Portugal. A full Moon appears when the whole side of Earth's natural satellite that faces our planet is lit by the Sun's rays. Following a lunar phase cycle doesn't make it any less impressive, especially when seen from this perspective.



SpaceX's Dragon docks

In a historic moment, the SpaceX Crew Dragon successfully docked with the ISS before the Falcon 9 which launched it returned to Earth for an upright landing. Here you can see the capsule arriving at the ISS on 16 November 2020 ahead of its docking at 23:01 EST. It was carrying NASA astronauts Michael Hopkins, Victor Glover and Shannon Walker and Japan Aerospace Exploration Agency astronaut Soichi Noguchi. A Falcon 9 rocket launched a cargo ship into orbit on 6 December loaded with more than 3,000 kilograms of spare parts, science equipment and supplies for the crew.

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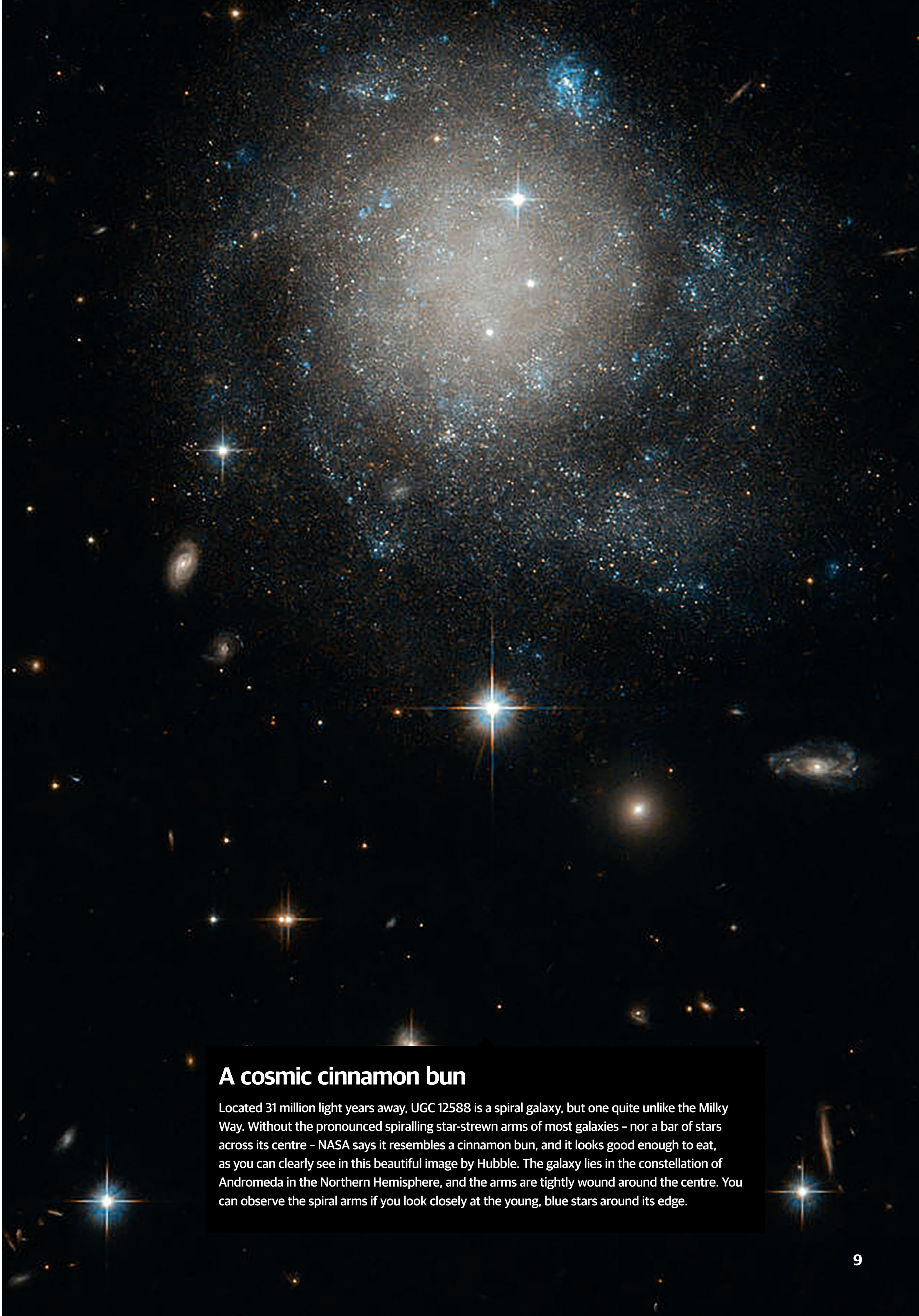

A cosmic cinnamon bun

Located 31 million light years away, UGC 12588 is a spiral galaxy, but one quite unlike the Milky Way. Without the pronounced spiralling star-strewn arms of most galaxies – nor a bar of stars across its centre – NASA says it resembles a cinnamon bun, and it looks good enough to eat, as you can clearly see in this beautiful image by Hubble. The galaxy lies in the constellation of Andromeda in the Northern Hemisphere, and the arms are tightly wound around the centre. You can observe the spiral arms if you look closely at the young, blue stars around its edge.

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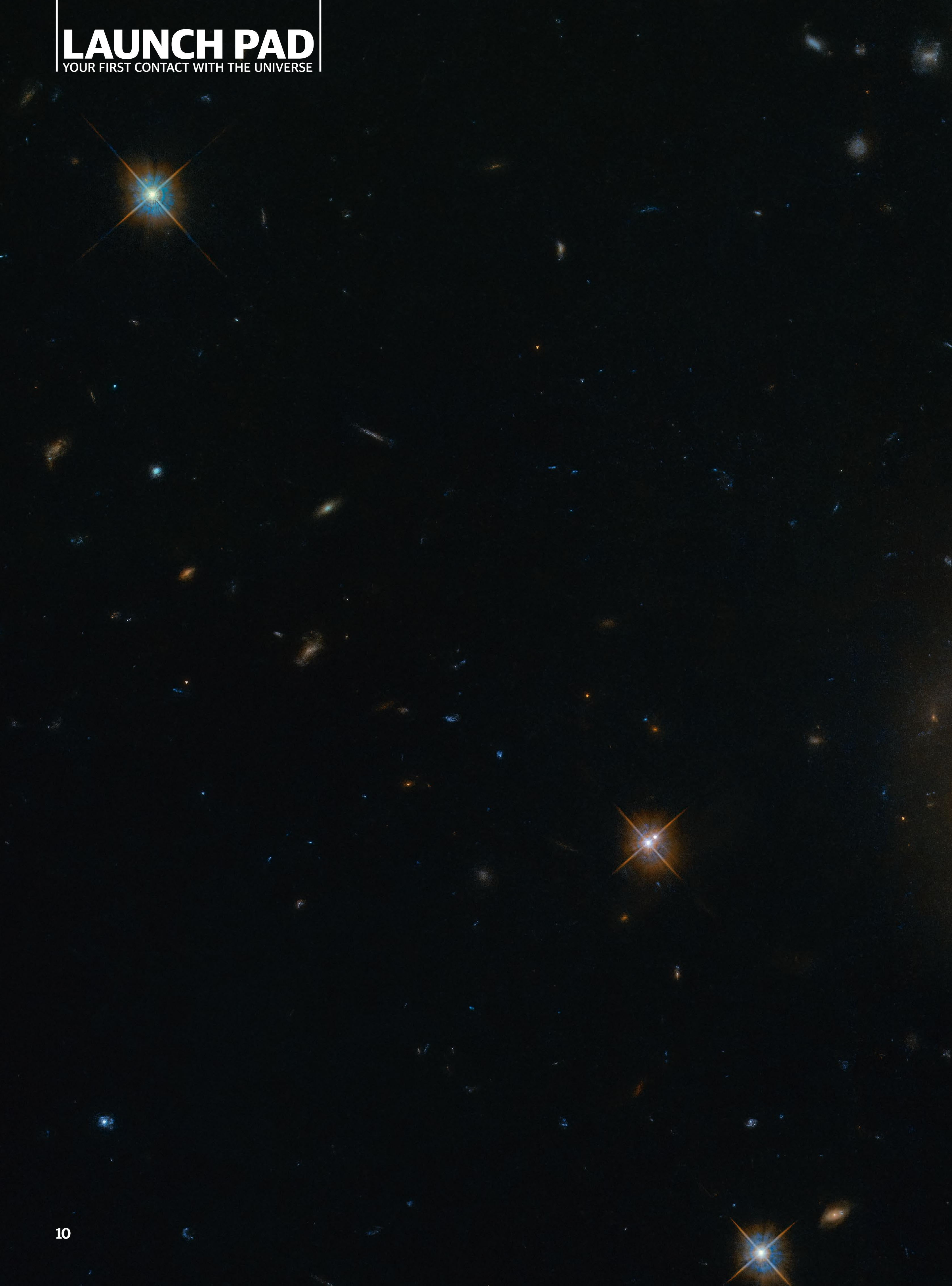

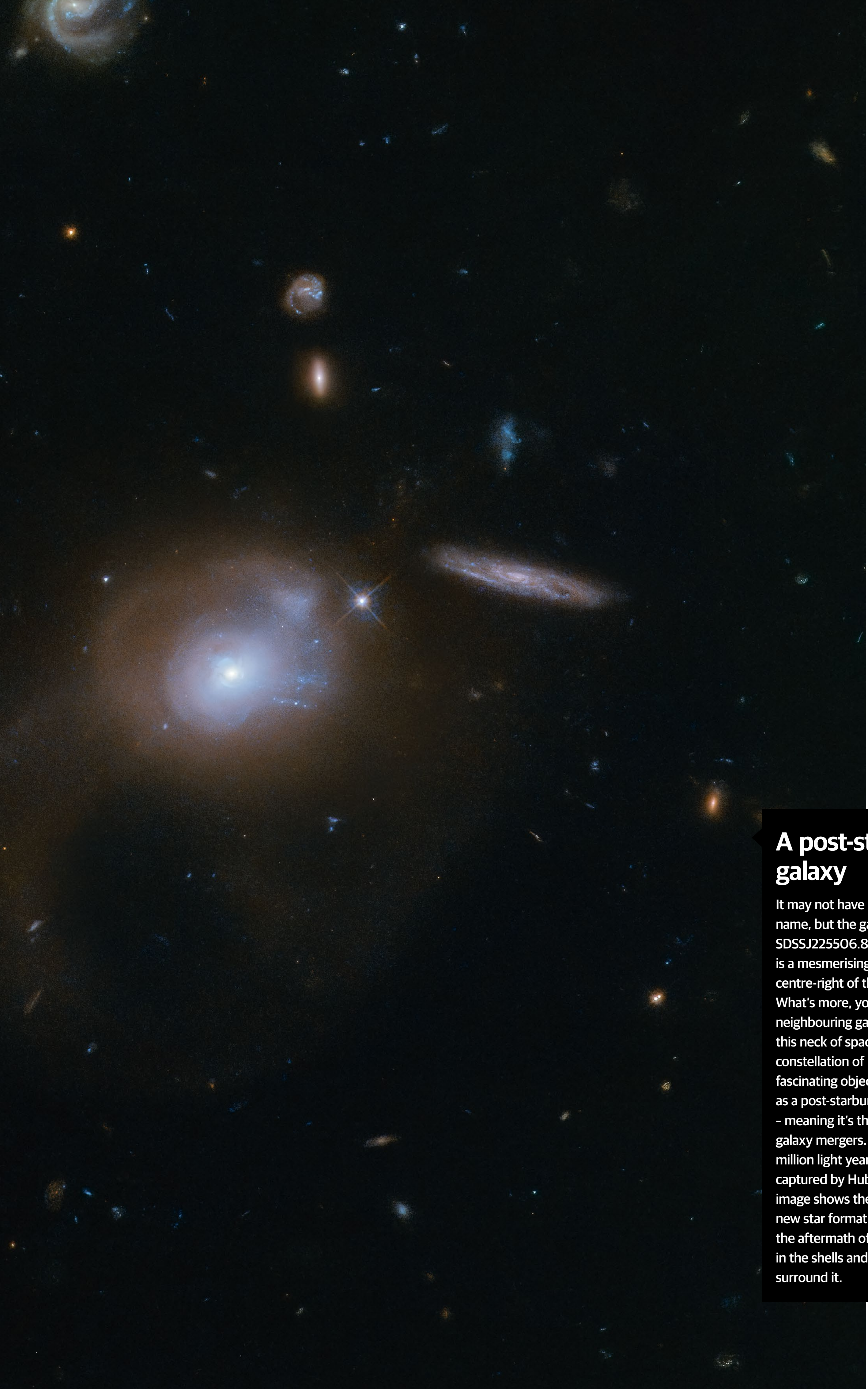

A post-starburst galaxy

It may not have a catchy name, but the galaxy SDSSJ225506.80+005839.9 is a mesmerising sight in the centre-right of this image. What's more, you can see neighbouring galaxies in this neck of space – the constellation of Pisces. This fascinating object is known as a post-starburst galaxy – meaning it's the result of galaxy mergers. Some 500 million light years away, it was captured by Hubble, and this image shows the bright core of new star formation along with the aftermath of the merger in the shells and tails that surround it.

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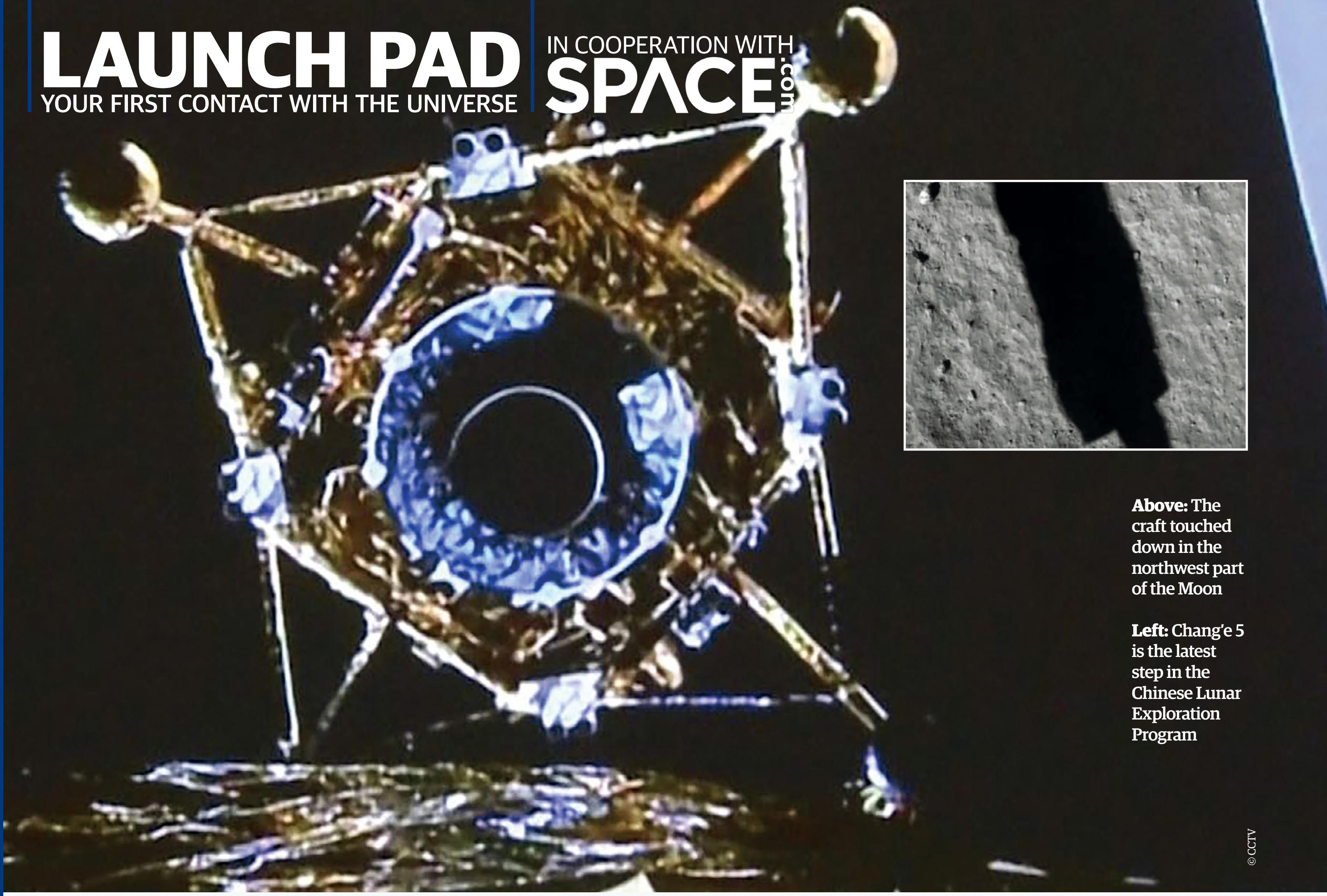

Above: The craft touched down in the northwest part of the Moon

Left: Chang'e 5 is the latest step in the Chinese Lunar Exploration Program

© CCTV

China's Chang'e 5 lands on the Moon, collects first lunar sample

Words by Mike Wall

China has landed on the Moon again, and this time the country plans to bring home some souvenirs. Chang'e 5, China's first sample-return mission, successfully touched down on 1 December near Mons Rümker, a lunar mountain located in the Ocean of Storms, or Oceanus Procellarum. The probe deployed its solar array and antenna soon after to begin its work.

Two pieces of the four-module Chang'e 5 mission hit the grey dirt after descent – a stationary lander and an ascent vehicle. If all goes according to plan, the lander will spend the next few days collecting about two kilograms of lunar material, some of it dug from up to two metres (6.5 feet) beneath the lunar surface.

The sample will then be transferred to the ascent vehicle, which will launch to lunar orbit and meet up with the other two Chang'e 5 elements – an orbiter and an Earth-return craft. The return vehicle will haul the Moon dirt and rocks back to our planet, with a touchdown planned in Inner Mongolia in mid-December.

That will be a landmark event, since pristine lunar samples have not been delivered to Earth since 1976, when the Soviet Union's Luna 24 mission came home with about 170 grams of material. Chang'e 5 just launched on 23 November, so it's packing a lot of action into a few short weeks. The compressed timeline is driven largely by the mission's energy needs: the Chang'e 5 lander is solar powered, so it must get all of its work done in two Earth weeks at most, before the Sun sets at Mons Rümker.

Though Chang'e 5 has a very short operational life, the mission is designed to have a long-lasting impact. After all, scientists are still studying the 382 kilograms of lunar material brought to Earth by NASA's Apollo missions from 1969 to 1972. Some of the Apollo material came from Oceanus Procellarum, a huge volcanic plain that Apollo 12 explored in late 1969. But Mons Rümker rocks formed just 1.2 billion years ago, whereas all of the samples collected by the Apollo astronauts are more than 3 billion years old.

Chang'e 5 "will help scientists understand what was happening late in the Moon's history, as well as how Earth and the Solar System evolved," the nonprofit Planetary Society wrote in its description of the mission.

> "IT IS SOLAR POWERED, SO IT MUST GET ALL OF ITS WORK DONE IN TWO EARTH WEEKS AT MOST, BEFORE THE SUN SETS AT MONS RÜMKER"

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Newfound 'Kraken merger' may have been the biggest collision in Milky Way history

Words by Brendon Specktor

The Milky Way has more than 100 billion stars, but it didn't come by them all honestly. At least a dozen times over the last 12 billion years, the Milky Way collided with a neighbouring galaxy and devoured it, swallowing up that neighbour's stars and mixing them into an ever-growing stew of pilfered suns.

With each galactic merger, the shape, size and motion of our galaxy changed forever, ultimately becoming the iconic spiral we recognise today. Now researchers have attempted to unwind that spiral.

Using artificial intelligence (AI) to match distinct clusters of stars by their ages, motions and chemical compositions, the team found evidence of five large-scale galactic mergers - each involving 100 million stars or more - dating back more than 10 billion years - including one ancient collision that has never been described before.

This newfound crash with the so-called Kraken galaxy not only helps fill in the Milky Way's mysterious family tree, but could also help astronomers piece together what our galaxy looked like in its earliest days. "The collision with Kraken must have been the most significant merger the Milky Way ever experienced," Diederik Kruijssen, an astronomer at the University of Heidelberg in Germany, said. "The merger with Kraken took place 11 billion years ago, when the Milky Way was four-times less massive [than today]. As a result, the collision must have truly transformed what the Milky Way looked like at the time."

Arecibo radio telescope hanging platform collapses

Words by Meghan Bartels

After two cable failures in the span of four months, Puerto Rico's most venerable astronomy facility, the Arecibo radio telescope, has collapsed in an uncontrolled structural failure. The United States' National Science Foundation (NSF), which owns the site, decided in November to proceed with decommissioning the telescope in response to the damage, which engineers deemed too severe to stabilise without risking lives. But the NSF needed time to come up with a plan for how to safely demolish the telescope in a controlled manner.

Instead, gravity did the job on the morning of 1 December, at about 08:00 local time, according to reports from the area. "NSF is saddened by this development," the agency wrote on Twitter. "As we move forward, we will be looking for ways to assist the scientific community and maintain our strong relationship with the people of Puerto Rico." The NSF added that no injuries had been reported, that the top priority was to maintain safety and that more details would be provided when confirmed.

None of the three towers collapsed fully, which was one of NSF's key concerns about leaving the structure as it was. Images do appear to show some damage in the knot of buildings at the base of one of the support towers, which includes administrative buildings and a public visitor's centre, although the buildings are still standing.

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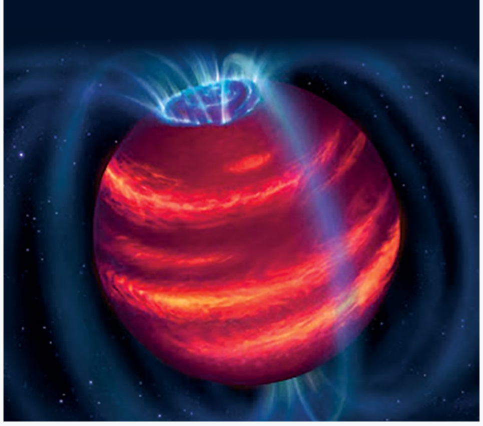
Faint 'super-planet' found by radio for the first time

Words by Samantha Mathewson

Scientists have discovered a cold, faint 'super-planet' that has remained elusive to traditional infrared survey methods. Observations from the Low-Frequency Array (LOFAR) radio telescope revealed a brown dwarf, designated BDR J1750+3809 and nicknamed Elegast. Brown dwarfs are sometimes referred to as failed stars or super-planets because they are too small to be considered stars, yet too big to be considered planets.

Generally, brown dwarfs are discovered by infrared sky surveys. Elegast, however, represents the first substellar object to be detected using a radio telescope, according to a statement from the University of Hawai'i. Since brown dwarfs are too small to become stars, they don't undergo the same nuclear fusion reactions that fuel bright stars, like our Sun. Therefore they are smaller, dimmer and colder than normal stars, making them harder to find using conventional methods, such as infrared instruments. However, brown dwarfs can emit light at radio wavelengths.

The researchers first discovered Elegast using the LOFAR radio telescope based in the Netherlands. Their observations were then later confirmed using the International Gemini Observatory in Hawaii and Chile and the NASA Infrared Telescope Facility, which is operated by the University of Hawai'i.



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Above: Brown dwarfs are huge, but didn't quite make it as stars

Jupiter's ocean moon Europa may spout water plumes

Words by Mike Wall

Jupiter's moon Europa may cough water into space from small pockets in its icy crust, a new study suggests. Europa, one of Jupiter's four big Galilean moons, harbours a huge ocean of salty water beneath its ice shell and is widely regarded as one of the Solar System's best bets to host alien life.

NASA's Hubble Space Telescope and other instruments have spotted evidence of sporadic plumes of water vapour that rise perhaps 200 kilometres (120 miles) above Europa's frigid surface. This water may be coming from the buried ocean, raising the exciting possibility that a spacecraft could sample this potentially life-supporting environment without even touching down on the moon.

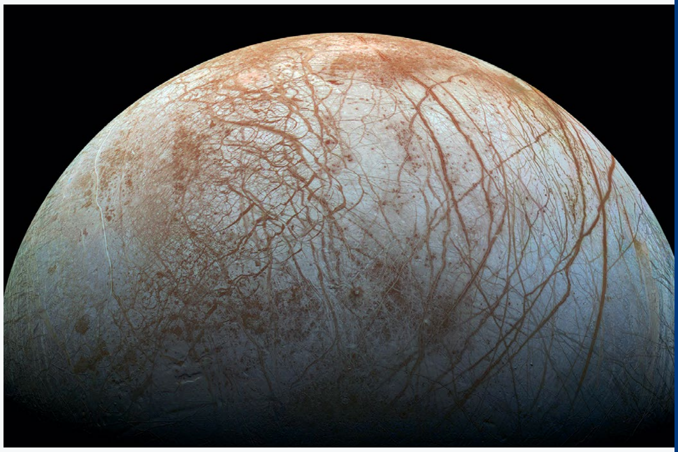
Those apparent big plumes may have smaller cousins, which are emanating from a source just below the surface. The researchers, led by Gregor Steinbrügge of Stanford University and Joana Voigt of the University of Arizona, analysed Europa's Manannán crater, a 29-kilometre (18-mile) wide feature created by an impact millions of years ago.

The heat generated by this impact doubtless melted a considerable portion of the nearby ice, and the researchers modelled what happened next. They found that some pockets of salty liquid brine likely survived for a spell after most of the meltwater had refrozen. In addition, the team determined that such pockets could move laterally through Europa's shell by melting some of the adjacent ice.

The modelling work further suggested that such migration happened at Manannán: a pocket probably made its way to the crater's centre and then began to freeze, causing a pressure build-up that eventually blasted out a roughly 1.6-kilometre (one-mile) high plume.

There is evidence that such a plume did actually exist – a spider-shaped feature at Manannán that was spotted by NASA's Galileo spacecraft, which studied the Jupiter system while orbiting the giant planet from 1995 to 2003. "Even though plumes generated by brine pocket migration would not provide direct insight into Europa's ocean, our findings suggest that Europa's ice shell itself is very dynamic," said Voigt.

Below: NASA plans to send its Europa Clipper to the icy moon some time in the next decade



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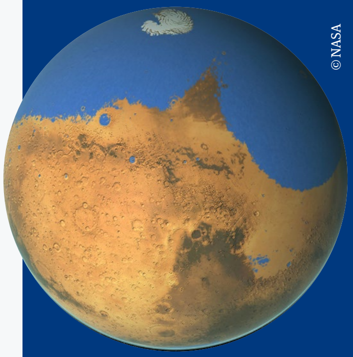

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Right: Dust storms are common on the arid Red Planet

Big dust storms may have driven off much of Mars' water

Words by Nola Taylor Redd

Dust storms fling water higher into the atmosphere than thought, helping strip Mars of its limited water and potentially contributing to the loss of an ocean's worth of water over billions of years. Summer dust storms can send water to the top of Mars' atmosphere, destroying the molecule and allowing hydrogen to escape.

Mars is thought to have supported an ocean or two in its early days. But the water that could have once kept the planet's surface habitable was lost. Researchers using NASA's Mars Atmosphere and Volatile EvolutioN spacecraft, or MAVEN, have learned that powerful summer dust storms may carry water above the hygropause, a cold layer in the atmosphere that traps water lower down.

"This process is slow and steady from Martian year to Martian year, so scientists have known for five to six years now that the classical model could not possibly be responsible for rapid variations in the [hydrogen] escape, which have been observed to occur on timescales less than a Martian year," said Shane Stone, a graduate student at the University of Arizona.

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DARK MATTER

WHERE DID IT COME FROM?

It's eluded us for decades, but bubbles could be the answer to the universe's most mysterious substance

Reported by Kulvinder Singh Chadha

© Tobias Roetsch

If something cast a shadow but you couldn't see it, you'd be intrigued. If it did that on the scale of the universe, you'd be perplexed. If you then couldn't find it despite your best efforts, you'd likely be frustrated. This is the situation that scientists looking for dark matter find themselves in. But dark matter doesn't even cast shadows; it's invisible to all electromagnetic radiation. And yet we have solid evidence that it exists. In fact, current calculations show that it comprises 80 per cent of all of the mass in the universe. Now a new study modelling dark matter as filtering through bubbles after the Big Bang may help point scientists in a new direction.

Although the mystery of dark matter can be traced as far back as Lord Kelvin, the modern breakthrough in research came in 1933. Fritz Zwicky was a Swiss astronomer working at the California Institute of Technology. Averaging the rotations of galaxies in the Coma Cluster, a large cluster of over a thousand galaxies, Zwicky noticed that their speeds were excessive. So much so, in fact, that the galaxies should have flown apart. There wasn't enough visible matter to gravitationally bind each galaxy together. He concluded that there must be a 'dunkle materie' - or 'dark matter' - component to them, which he calculated to be 400 times what could be seen. Modern calculations have lowered this value.

> "THE PUZZLE OF DARK MATTER FORCES US TO THINK IN NEW WAYS"
>
> MICHAEL BAKER

Six years later, American doctoral student Horace Babcock showed dark matter present in the Andromeda Galaxy. Curiously, it was more concentrated in the periphery of the disc than the centre. This was the first indication that galaxies had dark matter 'halos'. Then, in the late 1970s, American astronomers Vera Rubin and Kent Ford showed that galaxies contained between five and ten times more dark matter than luminous matter.

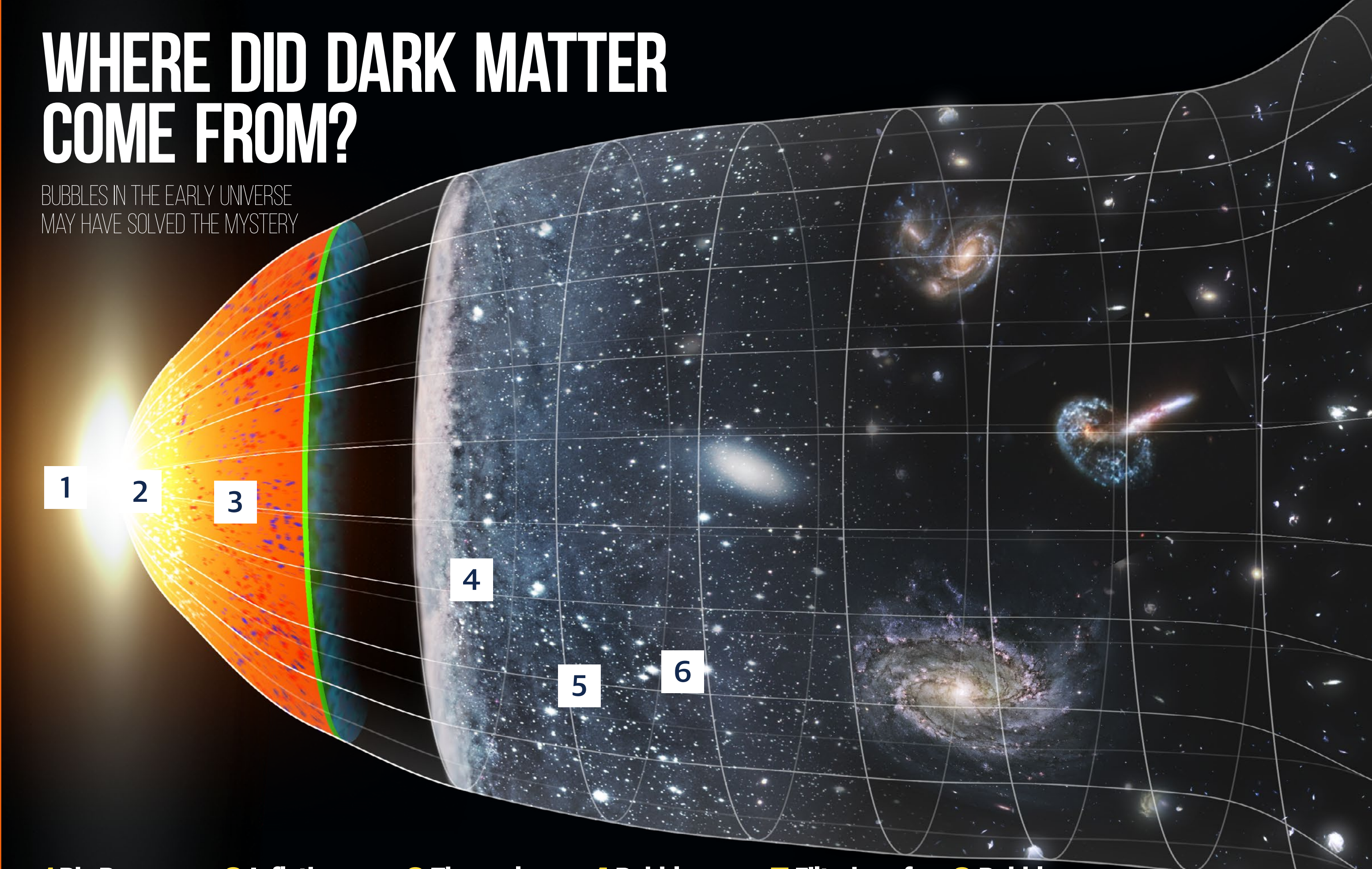
The term 'dark matter' is a slight misnomer. It isn't simply dark; it's completely invisible, no matter which part of the electromagnetic spectrum it's observed in. Its only observable effect is gravitational, much like how wind is only visible when it affects leaves, branches and hair. But this gives dark matter a dramatic quality, one predicted

Below: **Fritz Zwicky was the first scientist to measure the extent of dark matter in other galaxies**

© Getty

WHERE DID DARK MATTER COME FROM?

BUBBLES IN THE EARLY UNIVERSE MAY HAVE SOLVED THE MYSTERY



1 Big Bang occurs

The universe begins as an extremely hot, dense state.

2 Inflation happens

At 10^{-36} seconds the universe expands with unimaginable speed in a period known as inflation. This cools the universe further.

3 Thermal freeze out

Very quickly, the subatomic particles of ordinary matter 'freeze' out of the dense plasma as it cools. So does dark matter.

4 Bubbles form

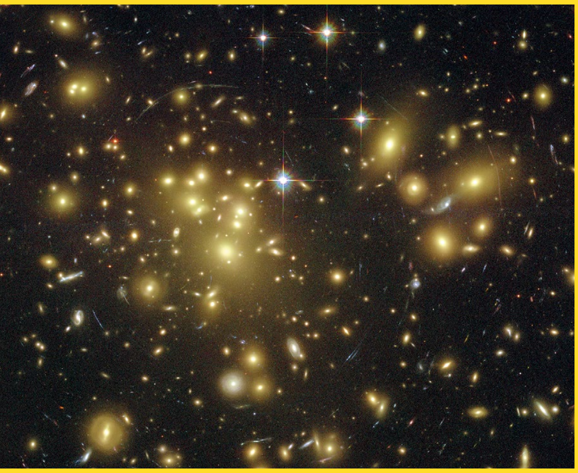
A particle called phi starts a phase change in the universe. These act as nucleation sites, growing as expanding bubbles.

5 Filtering of matter

Despite particles freezing out, they're still hot, including dark matter. Some of the latter pass into the bubbles and gain mass.

6 Bubbles merge

The bubbles merge, and the phase change completes. All the surviving dark matter particles are now part of the universe.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by Einstein and one that serves as another piece of evidence of its existence.

In 1915 Einstein presented his general theory of relativity, which models space and time – or just 'space-time' – in our universe as behaving like a stretched fabric warped by the presence of mass or energy. This warping of space-time in a mass' vicinity is the explanation for gravity. This is true of planets, stars, galaxies and entire galaxy clusters.

Multiple experiments have confirmed the theory with incredible accuracy. Although not the first to do so, in 1937 Zwicky realised the implications of Einstein's theory. The path of light would be curved by this warped space-time, meaning that whole galaxy clusters could be used as gravitational 'lenses'. It was another 42 years before this effect was observationally confirmed with the twin quasar QSO 0957+561 A/B, gravitationally lensed by the galaxy YGKOW G1. Since then gravitational lensing has become a tool to measure the extent of dark matter, such as in the galaxy cluster Abell 1689. But where did it come from? To answer that, we have to go back to the very beginning.

The universe started 13.8 billion years ago in an extremely hot, dense state, known colloquially as the Big Bang. This intense region, containing all of the energy of our entire universe, was far too hot and dense for matter to exist in any meaningful sense. There was constant creation and annihilation of particles. Then things happened very rapidly.

© Tobias Roetsch

© NASA/ESA & Hubble

Above: The quasar and its double image QSO 0957+561, detected in 1979, proved gravitational lensing

Bottom left: Gravitational lensing in the Abell 1689 cluster, caused by its dark matter

Between 10^{-36} and 10^{-32} seconds after the Big Bang, in a period known as inflation, the universe expanded 10^{26} times. Quarks and subatomic particles formed in the subsequent fractions of a second that followed. However, it was still too hot for protons and neutrons, which comprise ordinary atomic nuclei, to form. According to a lot of scientists, as expansion continued and the temperature dropped, subatomic and dark matter particles both condensed out of the cosmos' plasma, like ice crystals forming in a cloud.

These particles are often called 'thermal relics', since they are the leftovers of a higher temperature universe. The main example of thermal relic dark matter candidates are Weakly Interacting Massive Particles (WIMPS), which have been the source of most searches for this elusive substance.

But according to a new study, an alternative scenario may have played out. Instead of freezing out of cooling plasma, dark matter may have filtered out into bubbles that formed during what's known as a phase transition, when the universe changes its state from one form to another as it continues to expand. Examples of phase transitions abound in physics, including the early universe. One everyday example is boiling water. As water boils it changes phase from liquid to gas. This change can be seen in the water itself as bubbles of vapour form before escaping. Something similar occurred fractions of a billionth of a second after the Big Bang.

In the new study, published in *Physical Review Letters*, a trio of physicists working in Australia, Switzerland, Germany and Texas propose an additional new particle called phi. "The phase transition occurs when the phi field has a non-zero value in the lowest energy configuration - like the Higgs field today," says Dr Michael Baker of the University of Melbourne. In the early universe, these phi particles acted as nucleation sites, with their associated fields expanding like bubbles. Dark matter particles that formed in the super-hot, dense 'soup' of the universe collided with the bubble walls. Many simply bounced off, but some had enough momentum to pierce through into the bubbles. As they did so they gained more mass, because the particles were able to couple more strongly to the Higgs field, responsible for the Higgs boson.

The Higgs boson was discovered by the Large Hadron Collider (LHC) in 2012 and is what gives other particles mass. Due to conservation of energy, once inside these regions, now-massive particles

WHAT IS DARK MATTER?

It's not really 'dark', but it has some properties

It's the majority of matter

Invisible dark matter makes up 80 per cent of the mass in the entire universe.

It affects light

Because of general relativity, dark matter acts as a gravitational lens and 'bends' light.

It could be a new particle

Dark matter could be an undiscovered particle that hardly interacts with normal baryonic matter or radiation.

It could be a WIMP

Weakly Interacting Massive Particles, formed after the Big Bang, could be one explanation.

It could be an axion

Evidence for WIMPs is weakening, giving ground to axions as a possible alternative.

Newton's laws may need modifying

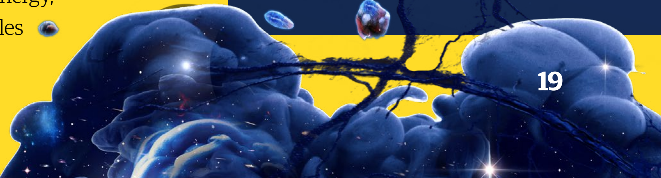
One alternative to dark matter is tweaking Newton's laws so that they behave differently at galactic edges.

It forms the universe's structure

Scientists think galactic clusters form in an existing 'dark matter web', forming the universe's large-scale structure.

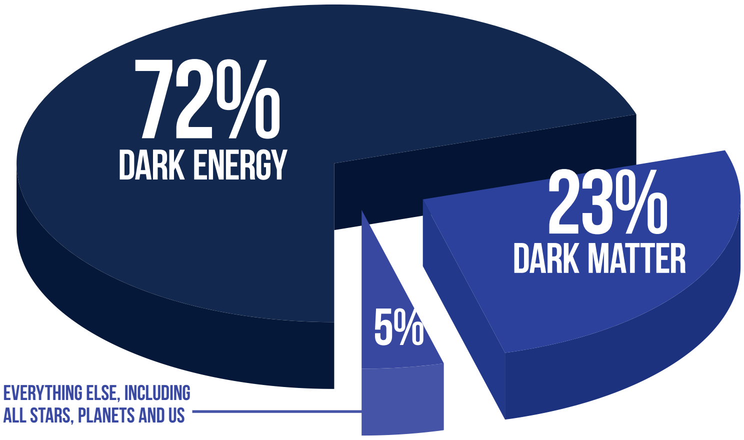
It's long lived

Axion dark matter could last 3,000 trillion years – roughly 220,000 times the current age of the universe.



DARK MATTER VS DARK ENERGY

Even more mysterious than dark matter is a phenomenon in the universe called dark energy

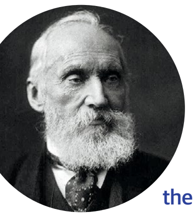


Invisible matter

Scientists think that dark matter may be like ordinary matter, only invisible and non-interacting. However, we don't know. We could be completely mistaken, and it could be something else entirely, yet to be theorised.

It has a gravitational effect

Like ordinary matter, its dark counterpart has a gravitationally attractive effect on its surroundings. This can be seen in the gravitational lensing of large galaxies and galaxy clusters.



It was seen in the 19th century

Lord Kelvin first noted the peculiar motions of stars in the Galactic Centre, concluding in 1884 that a large number of 'unseen dark bodies' were present and causing the gravitational effects.

Voyager 1 has disproved one theory

The Voyager 1 probe, now outside the Sun's heliosphere, would have been able to detect faint radiation from super-small black holes, a possible dark matter candidate. None was detected, disproving the theory.

It's visible in the Big Bang's echo

The cosmic microwave background, the relic radiation of the early universe, can show patterns relating to matter distribution. In particular, it can show how the universe's web of dark matter evolved over time.

It's speeding things up

In 1998, results from two separate instruments – one of which was the Hubble Space Telescope – showed that 5 billion years ago, the expansion of the universe started accelerating. The cause is labelled 'dark energy'.

It's most of the universe

According to data from NASA's Wilkinson Microwave Anisotropy Probe spacecraft, dark energy comprises an astonishing 72 per cent of the energy density of the entire universe. Dark matter comprises 23 per cent.

Einstein's mistake may not be wrong

Einstein's equations showed the universe was expanding when it was thought to be static. He introduced the cosmological constant to fix this. Later admitting it was a mistake, it may nonetheless explain dark energy.

Then again, it may be

From calculations, the cosmological constant is 120 orders of magnitude too large to explain observations. Fortunately there are other models for dark energy, including a proposed new fundamental force called quintessence. But there's no evidence yet.

We're trying to solve the mystery

The Dark Energy Survey (DES) is just one of many projects trying to uncover dark energy's secrets. In DES' case this involves mapping millions of galaxies and thousands of supernovae to see what they reveal.

Right: The IceCube Observatory hunts for neutrinos below the ice in Antarctica

© Rakshya Khatiwada, University of Washington

slowed down, dramatically reducing particle-antiparticle annihilations and thus cementing their place in the universe. The bubble expansions continued apace until they merged, enveloping the entire universe and leaving behind only those dark matter particles lucky enough to get in.

No one has yet been successful in detecting dark matter, so how would someone look for dark matter filtered by cosmic bubbles? "We consider the best prospects for finding evidence for our proposal are collider searches for the new [phi] particle, detection of dark matter annihilation products or detection of background gravitational waves," explains Baker. In the new study the authors state that particle-antiparticle annihilations in the galactic disc could give rise to neutrinos on the order of 10^{15} electronvolts. Such an event was observed by the IceCube Neutrino Observatory in Antarctica. But these events are rare, and may also come from other sources, such as supernovae.

What of colliders? In October 2020 the ATLAS collaboration at the LHC presented results using the Higgs boson itself as a tool for searching for dark matter. Rather than looking for dark matter directly, the ATLAS detector looked for signs of missing

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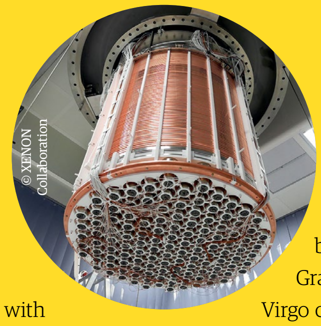

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momentum that could indicate its presence. Nothing significant was detected, but the branching fraction - the ratio of particles decaying into another particular one - was whittled down to a maximum of 0.11 - or 11 per cent - with 95 per cent confidence.

As Baker points out: "We used an earlier bound of 0.19 on the Higgs branching ratio, so that constraint is now a bit stronger, although our mechanism is still perfectly viable. Note that in our case it puts a bound on the new scalar particle [phi] in our model, which is not dark matter. The fermion 'chi' is, but the scalar would behave very much like dark matter if produced in a collider." So a detection of either would be a breakthrough. Such negative results are the mainstay of dark matter physics, but they are important for ruling out lines of enquiry and chasing up more promising leads.

What about the detection of gravitational waves - ripples in the fabric of space-time - that Baker mentions? The study specifically mentions possible use of the Laser Interferometer Space Antenna (LISA), a space-borne gravitational-wave observatory using laser interferometers spaced 2.5 million kilometres (1.5 million miles) apart. Gravitational waves were first detected by the ground-based LIGO (Laser Interferometer Gravitational-Wave Observatory) and Virgo collaboration in 2015. Due to launch in 2034, early universe phase transitions are one of LISA's science goals. Due to the expansion of the universe over time, any gravitational waves resulting from bubble formation would now have a huge amplitude, necessitating LISA's large span.

And what of the dark matter itself? Could the chi particles be WIMPS, or something else? As they 'froze out' from the cosmic plasma, WIMPS would

> "NEGATIVE RESULTS ARE THE MAINSTAY OF DARK MATTER PHYSICS, BUT THEY RULE OUT LINES OF ENQUIRY"

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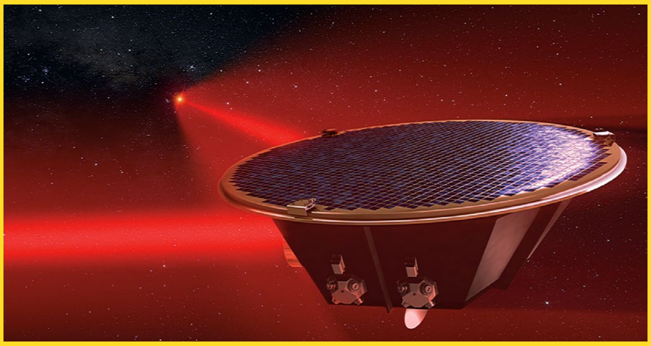
Left: The XENON1T experiment detected an excess signal, which currently remains unexplained

Right: Part of Washington University's ADMX haloscope, designed to detect dark matter axions



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Above: The proposed LISA mission could detect gravitational waves from primordial phase-change bubbles

be considered thermal relics. "Most of the major current experiments are searching for dark matter based on the hypothesis that it was produced in this way," says Baker. The bubble-filtered dark matter of the new study didn't form this way, however. "Recently attention has begun to shift focus to other production mechanisms; axion dark matter is an example of a non-thermal relic that is currently actively being searched for," he says.

Axions are a hypothetical particle first proposed to explain an unusual problem in quantum physics, and are now also a possible dark matter candidate. One operation looking for them is the Axion Dark Matter Experiment (ADMX) at Washington University. Some axions are supposed to turn into microwave photons in strong magnetic fields, so ADMX consists of a microwave cavity inside a superconducting magnet, called a haloscope.

So far the international team has ruled out low-mass axions. As Professor Gray Rybka of the University of Washington says: "ADMX is currently searching masses above 3.53 microelectronvolts, and we'll let the world know if we find anything! One interesting fact is that the expected axion signal, if we find it, should be very clear." But another axion detector has already seen something, which at the time of writing remains unexplained. The XENON1T detector, operated by INFN Laboratori Nazionali del Gran Sasso, Italy, recorded an excess signal between 2016 and 2018, first published in 2020. It's possible that it's due to the presence of tritium atoms in the ultra-pure xenon used, but nothing has been ruled in or out yet.

Follow-up experiments currently underway may provide a definitive answer. Something echoed by Baker, who's looking forward to following up his own work. "The experimental landscape is quickly changing, with huge progress having been made in the last 10 to 20 years. The puzzle of dark matter forces us to think in new ways, and even if these ideas turn out to be unrelated, they could provide the key to understanding some of the deepest mysteries in the universe."

Kulvinder Singh Chadha
Space science writer
Kulvinder is a freelance science writer, outreach worker and former assistant editor of *Astronomy Now*. He holds a degree in astrophysics.

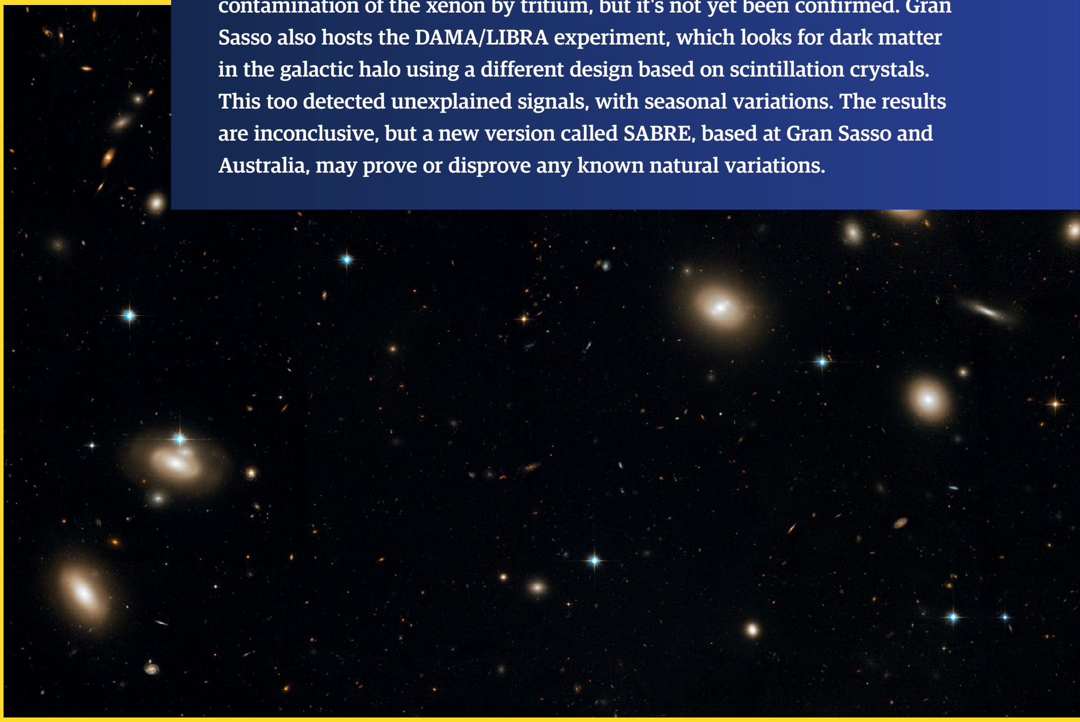
THE BIGGEST UNANSWERED QUESTIONS ABOUT DARK MATTER

Is there more than one kind?
Could there be an entire family of dark matter particles as opposed to just a single type? The Standard Model of particle physics says that ordinary matter is composed of electrons as well as the quarks that make up protons and neutrons. It also includes the fundamental force-carrying particles, such as photons, gluons, bosons and some other short-lived matter particles. Could there be a similar but separate model for dark matter?

Are there corresponding 'dark forces'?
Forget horror and fantasy here. If there are a range of dark matter particles, could they experience their own dark matter forces? If so, could that also sometimes affect ordinary particles? This is the hope of a collaboration working with the Super Proton Synchrotron at CERN. The team has examined billions of high-energy electrons, looking for an energy deficit in the resulting photons. The idea is that 'dark photons' would interact with normal photons and carry away some energy, thus showing themselves by their absence. Nothing's yet been detected, but the team will try again in 2021 after an upgrade.

Could it be responsible for the universe's matter?
In the very early universe, fractions of a second after the Big Bang, equal amounts of matter and antimatter should have been created. They then both should have annihilated one another, leaving a universe filled only with radiation. But the universe is filled with matter, with little sign of the missing antimatter. What led to this asymmetry is still one of the biggest mysteries in cosmology. Could dark matter be the culprit? The Baryon Antibaryon Symmetry Experiment at CERN is testing whether dark matter particles could interact preferentially with antimatter. This might account for the lopsidedness we see today.

Could it already have been detected?
The Gran Sasso National Laboratory in Italy hosts the XENON dark matter experiment, of which the XENON1T detector team announced an unexplained signal excess in June 2020. The possibility is that it could be due to contamination of the xenon by tritium, but it's not yet been confirmed. Gran Sasso also hosts the DAMA/LIBRA experiment, which looks for dark matter in the galactic halo using a different design based on scintillation crystals. This too detected unexplained signals, with seasonal variations. The results are inconclusive, but a new version called SABRE, based at Gran Sasso and Australia, may prove or disprove any known natural variations.



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Below: The Coma Cluster's galactic rotation curves show the presence of large amounts of dark matter

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EXPLORING HELL

Needing to navigate mechanical rovers on Venus, NASA offered a prize

As recently illustrated in the announcement of potential life signs, Venus harbours the most benign off-Earth environment in the Solar System. Some 30 kilometres (18.6 miles) high in the clouds it is one Earth atmosphere pressure and between 15 and 30 degrees Celsius (59 and 86 degrees Fahrenheit), yet the surface is the most hostile place in the Solar System.

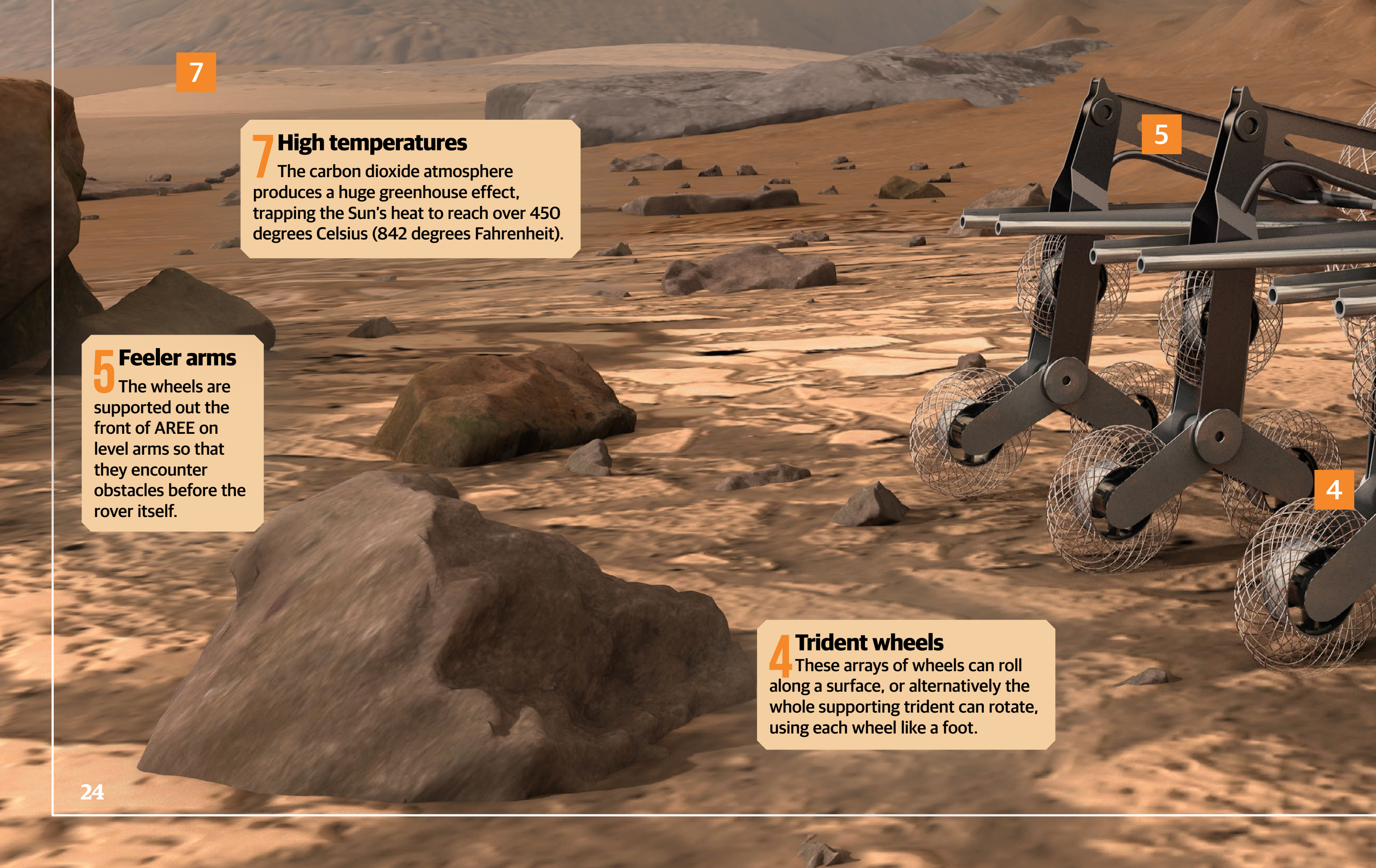
The dense carbon dioxide atmosphere, which produces the benign conditions higher up, traps in solar heat through the greenhouse effect. The surface temperature is hotter than the surface of Mercury, and hot enough to melt lead. The density of the atmosphere also makes the surface pressure 92 times that of Earth's, equivalent to nearly a kilometre (0.6 miles) deep in the ocean.

This harsh environment has severely limited our ability to explore the surface. The Soviets made a speciality of Venus exploration, sending 16 probes between 1961 and 1984. Faced with the heat and pressure, the longest any lander survived was 127 minutes. Seeking to return to Venus, survive longer and explore more of the surface, NASA issued a NASA Innovative Advanced Concepts (NIAC) grant to Jonathan Sauder for his ingenious Autonomous Rover for Extreme Environments (AREE) concept.

The greatest problem for Venus probes is the heat destroying their electronics, so AREE would be a clockwork rover, wound up by the strong carbon dioxide winds and employing mechanical systems where possible. Sauder has continued AREE studies with the Jet Propulsion Laboratory, studying walking or rolling rovers, different wind turbines, the possibility of sending data by semaphore and even engraving records to be launched off the surface by balloon. While some electrical systems are expected, NASA wants everything to be as mechanical as possible, so in February 2020 it issued a design challenge through the HeroX prize platform to ask engineers, makers, students and inventors across the globe to propose mechanical means of sensing and navigating AREE around obstacles. Now the winners have been chosen from 572 entries from 80 countries.

Third-placed Callum Heron, a mechatronics engineer from Brisbane, was inspired partly by his love of mechanical systems "I sometimes feel shortchanged as a mechanically focused mechatronics engineer that I wasn't born in the era of typewriters and automata. The idea of needing clock springs and Stirling engines to solve the world's problems is an inherently pleasant one to me, as strange as it must sound to normal people." Heron's system has an ingenious combination of different levers and probes to identify and respond to the different slopes and holes that the competition specified should make AREE reverse.

Second place went to Team Rovertronics, who designed a specially shaped framework that can slide over smaller obstacles but lift and engage an actual clockwork spring mechanism to command the rover to reverse or divert.



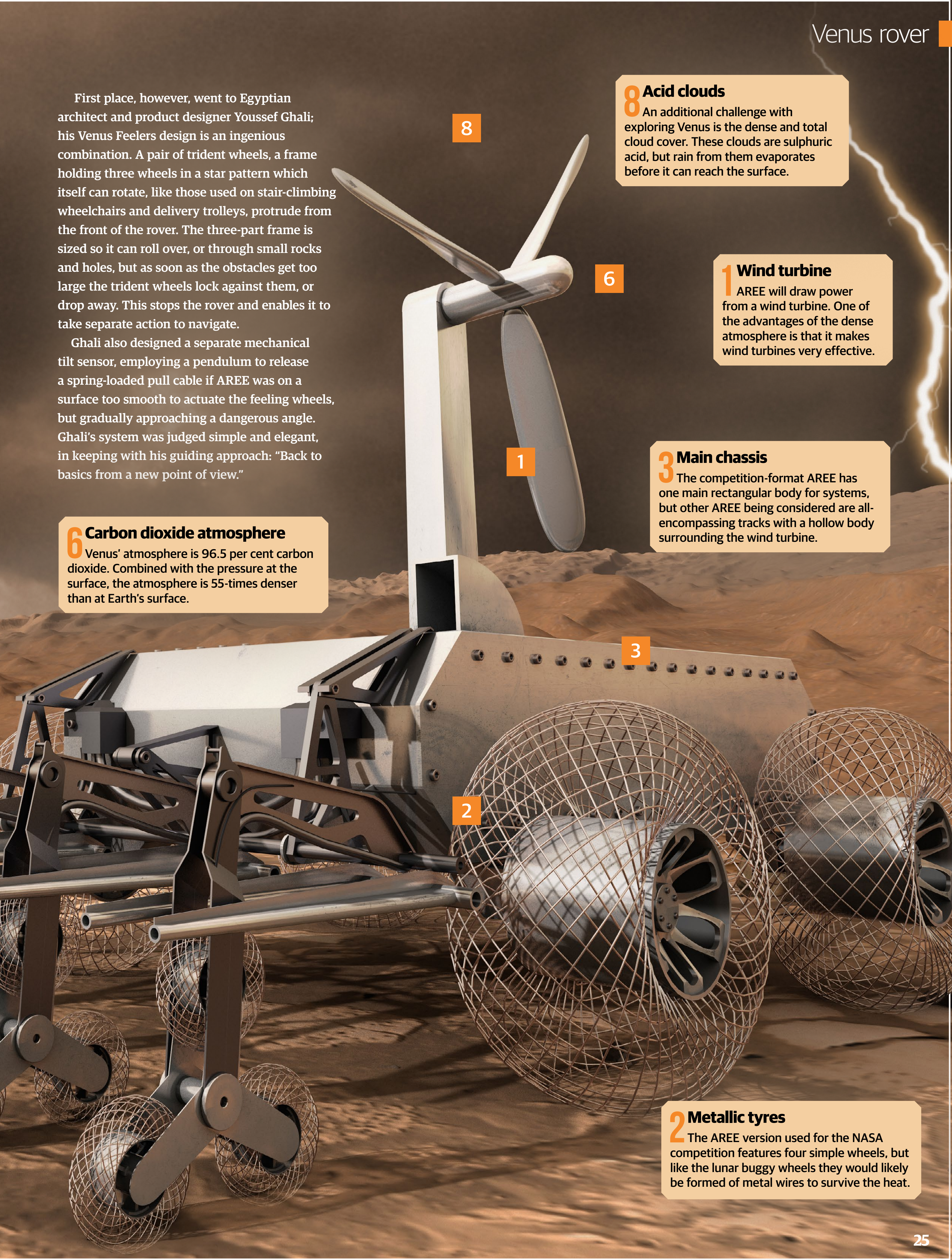
7 High temperatures
The carbon dioxide atmosphere produces a huge greenhouse effect, trapping the Sun's heat to reach over 450 degrees Celsius (842 degrees Fahrenheit).

5 Feeler arms
The wheels are supported out the front of AREE on level arms so that they encounter obstacles before the rover itself.

4 Trident wheels
These arrays of wheels can roll along a surface, or alternatively the whole supporting trident can rotate, using each wheel like a foot.

First place, however, went to Egyptian architect and product designer Youssef Ghali; his Venus Feelers design is an ingenious combination. A pair of trident wheels, a frame holding three wheels in a star pattern which itself can rotate, like those used on stair-climbing wheelchairs and delivery trolleys, protrude from the front of the rover. The three-part frame is sized so it can roll over, or through small rocks and holes, but as soon as the obstacles get too large the trident wheels lock against them, or drop away. This stops the rover and enables it to take separate action to navigate.

Ghali also designed a separate mechanical tilt sensor, employing a pendulum to release a spring-loaded pull cable if AREE was on a surface too smooth to actuate the feeling wheels, but gradually approaching a dangerous angle. Ghali's system was judged simple and elegant, in keeping with his guiding approach: "Back to basics from a new point of view."



8 Acid clouds
An additional challenge with exploring Venus is the dense and total cloud cover. These clouds are sulphuric acid, but rain from them evaporates before it can reach the surface.

1 Wind turbine
AREE will draw power from a wind turbine. One of the advantages of the dense atmosphere is that it makes wind turbines very effective.

3 Main chassis
The competition-format AREE has one main rectangular body for systems, but other AREE being considered are all-encompassing tracks with a hollow body surrounding the wind turbine.

6 Carbon dioxide atmosphere
Venus' atmosphere is 96.5 per cent carbon dioxide. Combined with the pressure at the surface, the atmosphere is 55-times denser than at Earth's surface.

2 Metallic tyres
The AREE version used for the NASA competition features four simple wheels, but like the lunar buggy wheels they would likely be formed of metal wires to survive the heat.

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BIO

Dr Bernard Harris Jr.

Harris is a veteran astronaut, logging over 438 hours in space in two Space Shuttle missions: STS-55 and STS-63, serving as a mission specialist and payload commander, respectively. During STS-63, Harris became the first African-American to perform a spacewalk. Having left NASA in 1996, Harris is now Chief Executive Officer at National Math and Science Initiative (NMSI).

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DR BERNARD HARRIS JR.

"WE STILL NEED TO HAVE MORE DIVERSITY IN THE ASTRONAUT CORPS"

A veteran astronaut now serving as a flag bearer for STEM education, Dr Bernard Harris Jr. speaks to **All About Space** about his time as a Space Shuttle astronaut, coloured representation in the current astronaut corps and whether he'd still like to go to the Moon

Interviewed by Lee Cavendish

What inspired you to become an astronaut?

The main inspiration was when we landed on the Moon in 1969, and I watched Neil Armstrong and Buzz Aldrin take the first steps on the Moon. I was excited about following in their footsteps. I was 13 years old at the time. And so I got a chance to see that and be inspired, even though I was looking at it on black-and-white television because that's all we had back in that day.

And turning that dream into a reality, was that an extremely difficult journey?

Yeah, a journey to become an astronaut is not an easy one. And I'm smiling as I'm saying that. It's so easy to see something that you like and that you want to do and have a dream of maybe one day doing that. It's a different story in making that dream a reality. And with that said, you can never accomplish anything without having a dream, or goal, of doing it, and so that goal led me to do a little research on what it took to be an astronaut.

I found out very early that I needed to finish old middle school, as we have in the United States, and high school and go to college. And not only just college but major in things that would be looked at favourably by NASA. And so in high school, I decided that I would go into medicine, in part because I was inspired by a mentor who is an African-American physician in San Antonio, Texas, and also by watching the space program and watching a doctor by the name of Joe Kerwin, who was the first American physician to travel in space.

On your first mission, STS-55, you spent ten days in space conducting roughly 90 scientific experiments. How did you manage to do so much in such a relatively short amount of time?

When you go into space, especially during the time in which we were flying the Space Shuttle, first of all, you've got limited space. We did happen to take a laboratory, so we had the ability to take more experiments on orbit, so that's why you ended up with 90 experiments [being conducted]. And your time is limited, right? So you know that you're going to be up there for a period of time having to conduct a myriad of experiments.

And so from the moment in which you liftoff to the moment at which you touch back down to Earth, your time is very valuable. It is mapped out and scheduled - even the time that you're going to eat, the time that you're going to sleep, and the time that you're going to do all those different experiments. Someone asked me to say, in a word, after the mission what was I feeling; exhausted, of all the work that you have to do in that limited period of time. But it was at the same time very exciting to do something that very few people have done before.

Did you have any time set aside where you could just look outside, look at the Earth in front of you and just breathe it in?

Definitely. Usually at the end of the day, when you finish up the main work and it's time to have your dinner, I would take my meal on the flight deck so that I could look out the windows of the flight deck and be able to take it all in. As you've done your research, you know that we go around the world every 90 minutes, and we see a sunset or sunrise every 45 minutes, so the views were incredible. That would be my way in which to unwind, of the sort, as I looked at the Earth beneath us.

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Left: Harris performed his historic spacewalk on 9 February 1995

Right: The Apollo 11 Moon landing was Harris' inspiration, much like many other astronauts and space enthusiasts

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> “I BELIEVE WE OUGHT TO BE EXPLORING SPACE AS EARTHLINGS, OR HUMAN BEINGS, RATHER THAN COUNTRIES”

Your second mission, STS-63, was one that had a fair few milestones. It had the first female pilot, Eileen Collins; it was the second time a Russian cosmonaut, Vladimir Titov, had flown on the Space Shuttle; there was the first UK-born astronaut, Michael Foale; and you were the first African-American to perform a spacewalk. Were the milestones met on this mission representative of a progressive and revolutionary period within NASA and the Space Shuttle program at the time?
Yeah, and Eileen Collins would, later on, become the first female commander of a Space Shuttle mission. It was a wonderful mission of firsts. I don't think that anyone of us thought about that, on this mission, we were going to make history. We were solely focused on the objective of the mission, which one of the main objectives, of course, was to go to the Russian space station.

Now you look back, do you think it speaks volumes about how NASA was progressing?
Yes, definitely. Because after that we have supported female pilots and commanders and mission specialists. After that, the international program grew considerably. Now there is the International Space Station where we have crew members from all over the globe and, after my walk certainly, we've had a number of African-American astronauts and astronauts of colour, I should say, that have participated not only in spaceflight but also who have done spacewalks and contributed to that construction of the International Space Station.

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What have your experiences been like as an African-American astronaut at NASA?
I think that's a great question given the discussion about systemic racism, not only in the United States but in the UK and all around the world. I would say that NASA is no different to many other institutions. A little bit more progressive in terms of our ability to be inclusive, because we have to be. I firmly believe that, and this is my opinion, that we ought to be exploring space as Earthlings, or human beings, rather than countries and certainly not due to the colour of our skin. That should be irrelevant. And thanks to all of the international work, and the work that we've been doing, I think that has now become a reality within the space agency.

Do you think there is sufficient coloured representation among the current crop of astronauts?
Well, I would say that we still need to have more diversity in the astronaut corps. Certainly, there are not a lot of African-American astronauts. I think we're close to now over 500 astronauts internationally, that have gone into space, and there's probably about 23 or 24 astronauts in the whole history of the program who are Black.

With the Black Lives Matter movement at the forefront this year, which has been very enlightening and positive, what kind of impact could this have on the world of STEM education?
Well, I think it underscores the issues that we're all having to grapple with here. But Black people in this country [United States] have not been treated fairly and it has been written about by many more people than me. That's due to systemic racism. That is one of those things that came about because we're not familiar with the culture. We all have stereotypes and biases and those things exhibit in the organisations that we are part of. And so the only way that we can solve that is to first be cognisant of it, to realise that it does happen, to realise that we, as human beings, are all subject to those biases that impact how we interact with each other.

What kind of advice could you give to any young adults that have an interest in a STEM subject and a desire to become an astronaut?
Well, I remind them of who they are in terms of their core. I believe that we're all born with great potential; I call it being multi-potential. So it's just up to us to figure out and accept the fact that we are multi-potential and that we are born with certain talents and skills. And our job in this life is to figure out how to use those skills to advance ourselves and our community. And then lastly, remind them that we all are born for a reason. I believe that there are mistakes in this world. I think we're all born to do certain tasks, a certain job, to accomplish a certain goal. If we discover what that is, then we've become valuable contributors to our communities and to our nations, and so it's important. All of those things require that you choose to realise your potential, that you choose to use your talents, and that you choose to make a difference in your life and the community around you.

With your two missions, was there a difference in the way that you felt sitting on the rocket, ready to launch off the second time?
Yeah. The second time was much easier in several respects. It's like riding a bike. Once you learn how to ride a bike, then it becomes very easy. Even if you may be away from it for a while to get on the bike, and feel like, you know, I know this, I've been here, I've done this. And so there was a lot less anxiety at liftoff versus your first time being on a rocket. Even though you've gone through years of training, that first time is pretty stressful and exciting. You have trained in different aspects of it, but you don't really know. This is your first time having that ride - and what a ride it is! It's very eye-opening.

The other thing that made the first one a little bit harder is that we had several attempts before we actually went into space. When I got assigned to the mission, we were supposed to liftoff nine months later, and two and a half years later, we took off. But in that time, the shuttle program went through hydrogen leaks in the engines that they had to solve, which delayed not only our mission but many others. And then we actually went into quarantine, preparing to launch, three times before the mission.

What causes more anxiety: liftoff or returning to Earth?
Liftoff. Just because it is such a physical experience. You know, because you're taking off, you're getting into space in eight and a half minutes. There is a lot of energy being dissipated as you're being blasted off into space. The first stage is riding solid rocket motors, and they kick out 6 million pounds apiece. Combined with the engines on the Space Shuttle, that's 7.5 million pounds of thrust, and you feel every pound of that thrust in your back as you're being catapulted into space.

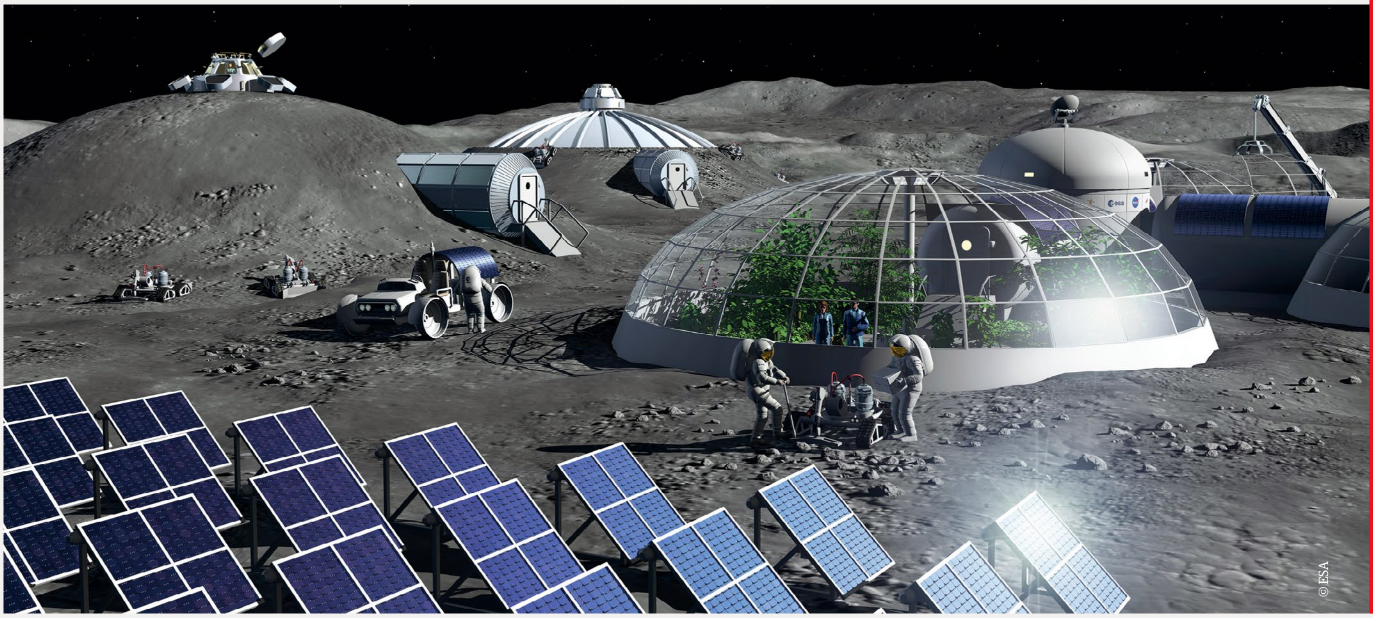
Then the second stage is a lot smoother because now you're only riding 1 and a half million pounds, but you've been given a great push on the solid rocket motors, so it gets a lot quieter. But still, because you're above the atmosphere and heading into space at that point, because we do that around 100,000 feet [30.5 kilometres], we begin to speed up. So now you're dealing with the physical sense of getting heavier and heavier as you're accelerating more and more, until you get to the main engine cutoff. Then at the main engine cut-off, you go from the noise, the physicality of all of that, to zero gravity within an instant and things begin to rise up around you, and you realise that you're in orbit.

NASA wants to return to the Moon by 2024, which is going to take a lot of STEM thinkers behind the scenes. How important are the people behind the scenes for a space program?
I can't go into space without the thousands of folks that are supporting me. Those that are engineers and scientists, who are looking at various aspects of what it takes to get us to orbit and projections, propulsion systems, electrical systems and environmental systems, once you get into orbit, and then being able to have constant communication and monitoring that occurs. So all of that requires folks on the ground, providing that type of support, and most of those folks have STEM backgrounds. And so their expertise is of most importance for a successful mission or any program.

Going to the Moon, as you mentioned, is something that we are looking forward to as an agency, and as an astronaut. That was my inspiration. The idea that we're now going to return to the Moon - and this time not just to leave footprints in the sand and plant a flag, it is actually to live on the surface, which will be the platform for us going deeper into our Solar System.

If NASA asked you to be one of the astronauts to go to the Moon, would you oblige?
I would love to go back. I would stop everything and get right back in line for that. With that being said, if they called me and said we want you to go to Mars, I would say no.

The difference is that the Moon has always been my aspiration, which is something that I would love to accomplish before I leave this planet, as a human being. Mars is just a little bit too long for me. And I always joke and say, now if I was 80 years old, I would probably go because I wouldn't be worried about coming back.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Right: Harris says that the future exploration of space should be conducted by human beings and not dependant on countries

A new theory suggests 'moonfalls' may have formed our planet's first continents

DID MINI-MOONS MAKE THE EARTH?

Reported by Libby Plummer

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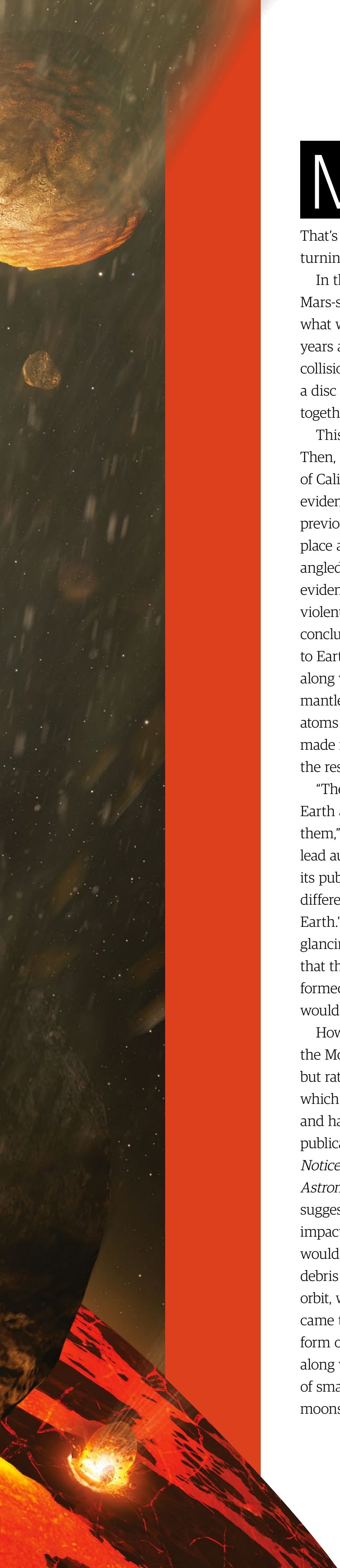


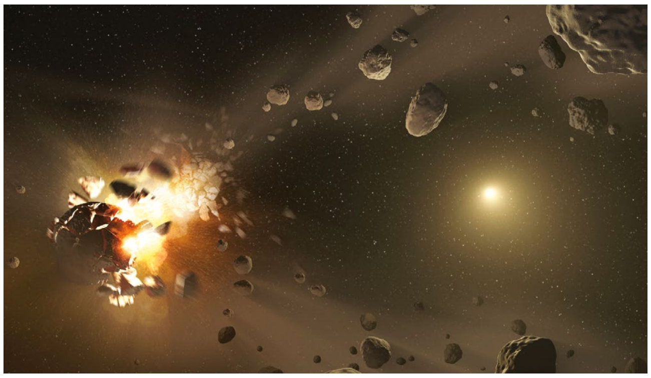
Mini-moons may have battered Earth with debris in its formative years, shaping the young planet and maybe even building the first continents. That's the theory put forward by a new study, turning the 'giant-impact hypothesis' on its head.

In the well-established giant-impact theory, a Mars-sized rocky object called Theia smashed into what would become Earth around 100 million years after the Solar System was formed. The giant collision spewed debris up into space, forming a disc of debris, some of which gradually came together to form our Moon.

This idea was initially put forward in 2012. Then, four years later, researchers at the University of California, Los Angeles (UCLA) published new evidence to cement the theory. While it was previously thought that the collision, which took place around 4.5 billion years ago, was a powerful, angled side-swipe by the giant rock Theia, the new evidence confirmed it was likely to have been a violent, head-on smash. The team came to this conclusion after analysing seven rocks brought back to Earth by the Apollo 12, 15 and 17 lunar missions, along with six volcanic rocks from the Earth's mantle. A shared chemical signature in the oxygen atoms both in the Moon rocks and the Earth rocks made it likely that a head-on collision had occurred, the researchers concluded.

"Theia was thoroughly mixed into both the Earth and the Moon, and evenly dispersed between them," said Edward Young, UCLA professor and lead author of the study, speaking at the time of its publication. "This explains why we don't see a different signature of Theia in the Moon versus the Earth." The study explains that the alternative, a glancing side blow from Theia, would have meant that the vast majority of the Moon would have been formed from Theia, and thus the Earth and Moon would have different chemical 'fingerprints'.

However, a series of recent studies argue that the Moon wasn't formed by a single collision alone, but rather a series of impacts. This research, which has been published online and had been accepted for publication in the *Monthly Notices of the Royal Astronomical Society*, suggests that multiple impacts on Earth would have blown debris back into orbit, which then came together to form our Moon, along with lots of smaller mini-moons, or 'moonlets'.



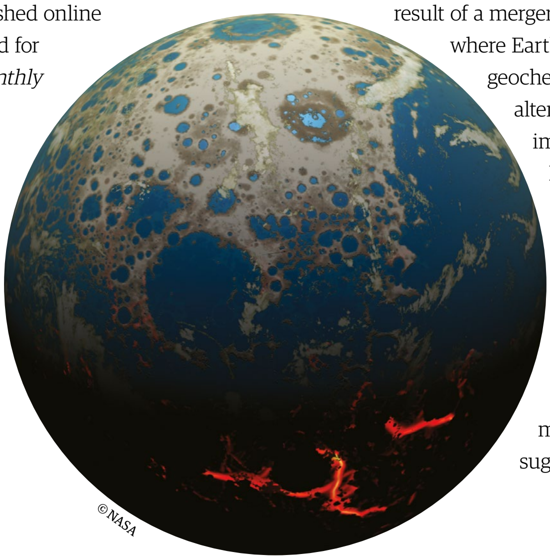
Above: Falling mini-moons could be responsible for the formation of Earth's earliest continents

Complex movement between these moonlets would have slowly changed their orbits, gradually making them more elliptical. Many of them would then have crashed down onto the proto-Earth, battering the fledgling planet time after time. These 'moonfalls' would have caused a build-up of material in localised spots, leading to the formation of topographical features and potentially even the Earth's first continent. The researchers were able to demonstrate the hypothesis using a series of simulations. The study was based on smoothed-particle hydrodynamical (SPH) simulations, where a computer is used to reproduce processes such as star formation and meteor impacts.

This theory was put forward as the researchers believe that the widely accepted idea of how the Moon was formed doesn't quite add up. "The current [giant-impact] paradigm is intrinsically incomplete and disconnected from the wider picture of terrestrial planet formation, in which the proto-Earth had experienced and grown though multiple planetary-scale impacts," co-author of the study Hagai Perets from the Technion Israeli Institute of Technology explains to **All About Space**. "Consideration of only the last such impact in the current paradigm disregards the critical evolution taking place prior to - and possibly following - this event."

That's why the researchers investigated the new scenario, in which Earth's Moon may be the result of a merger of lots of mini-moons, where Earth's geophysical and geochemical make-up were altered by the multiple-impact evolution of the Moon.

"The current paradigm is challenged by several major difficulties, as mentioned in this and previous papers," says Perets. "Generally, the multiple-impact model we suggest naturally connects



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Left: Earth was battered by asteroids during its formation

Earth's Moon formation with the global formation of the Solar System, and potentially constrains it. These issues and challenges call for a paradigm shift and motivate the novel conceptual framework we propose. The current research on Earth-Moon collisions is one piece in this new model, and we are working on several other implications, such as studying Moon-moon collisions."

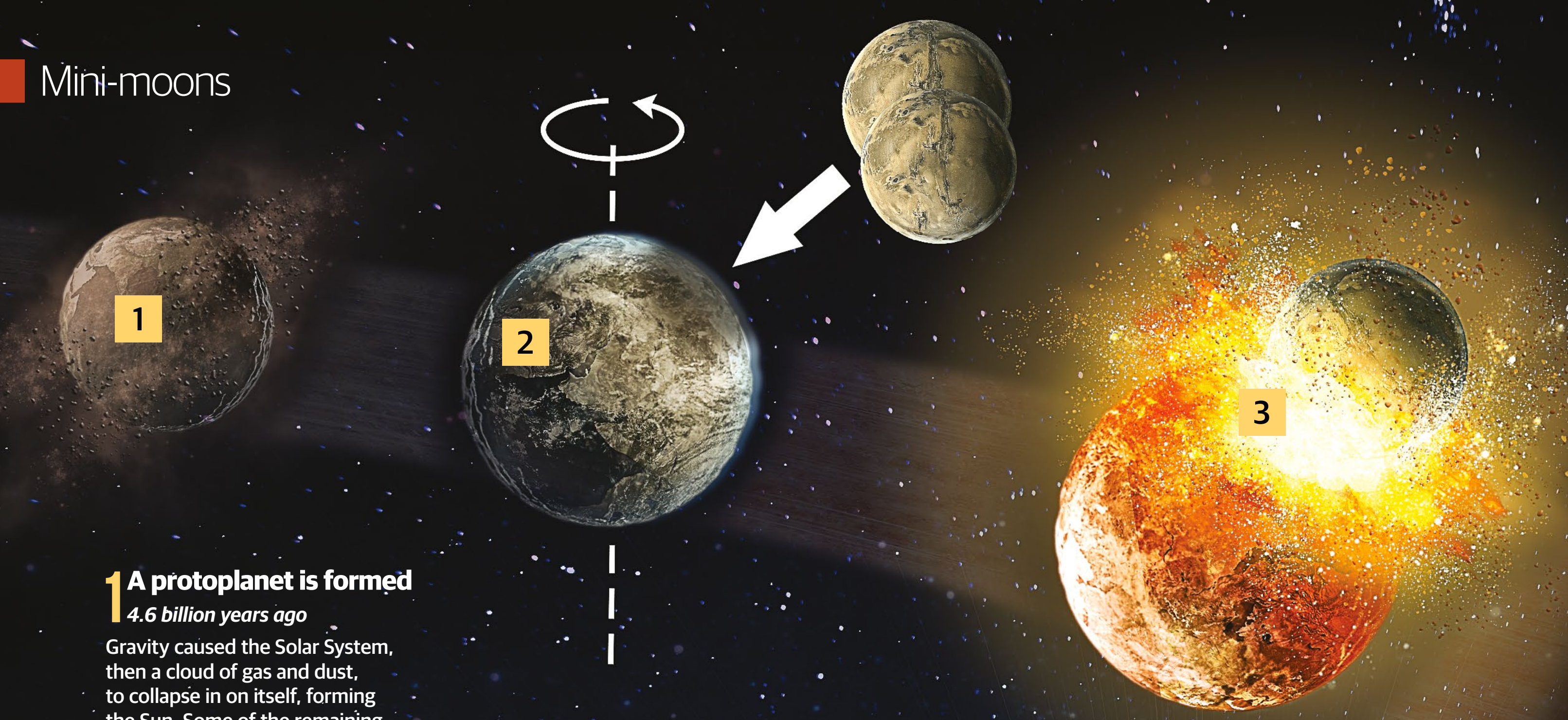
The theory builds on research published in 2017 from Perets and a different inter-university team which challenges the most prevalent theory of how the Moon formed. It suggests that the Moon we see is not Earth's first moon, but the latest in a series of rocky satellites, and that it was formed by a series of impacts rather than one big smash.

While the idea of one major collision is currently the accepted theory, the researchers behind recent studies claim that this scenario requires very specific conditions, which are rare. They claim that the idea of a series of impacts is far more feasible.

"The multiple-impact theory is a more natural way to explain the formation of the Moon," Raluca Rufu from the Weizmann Institute of Science tells **All About Space**. "It does not require one single and specific impact, but rather incorporates all the possible impactors Earth experienced during the late accretion stage [when Earth was formed]. Each moonlet accretes from a different debris disc and eventually merges with previous existing moonlets at low velocities, where the mixing between the two components is not efficient. This can explain some of the observed lunar heterogeneities in the Moon's interior," said Rufu, lead scientist of the research study published in *Nature Geoscience* in 2017.

THE MAKING OF EARTH

The nebular hypothesis is the most widely accepted theory of how our planet formed at roughly the same time as the rest of our Solar System's worlds



1 A protoplanet is formed

4.6 billion years ago

Gravity caused the Solar System, then a cloud of gas and dust, to collapse in on itself, forming the Sun. Some of the remaining material accumulated to form the Earth's rocky core.

2 The giant-impact hypothesis

4.5 billion years ago

A Mars-sized rocky object known as Theia smashed into the proto-Earth, catapulting pieces of the young planet's mantle into space. Some of these pieces merged to form our Moon.

3 Meteorite collisions

4.5 to 3.8 billion years ago

Earth developed into a solid sphere after being bombarded by the remaining debris in the form of asteroids, meteors and comets, which likely deposited much of the Earth's water onto its surface.

9 Pangaea formed

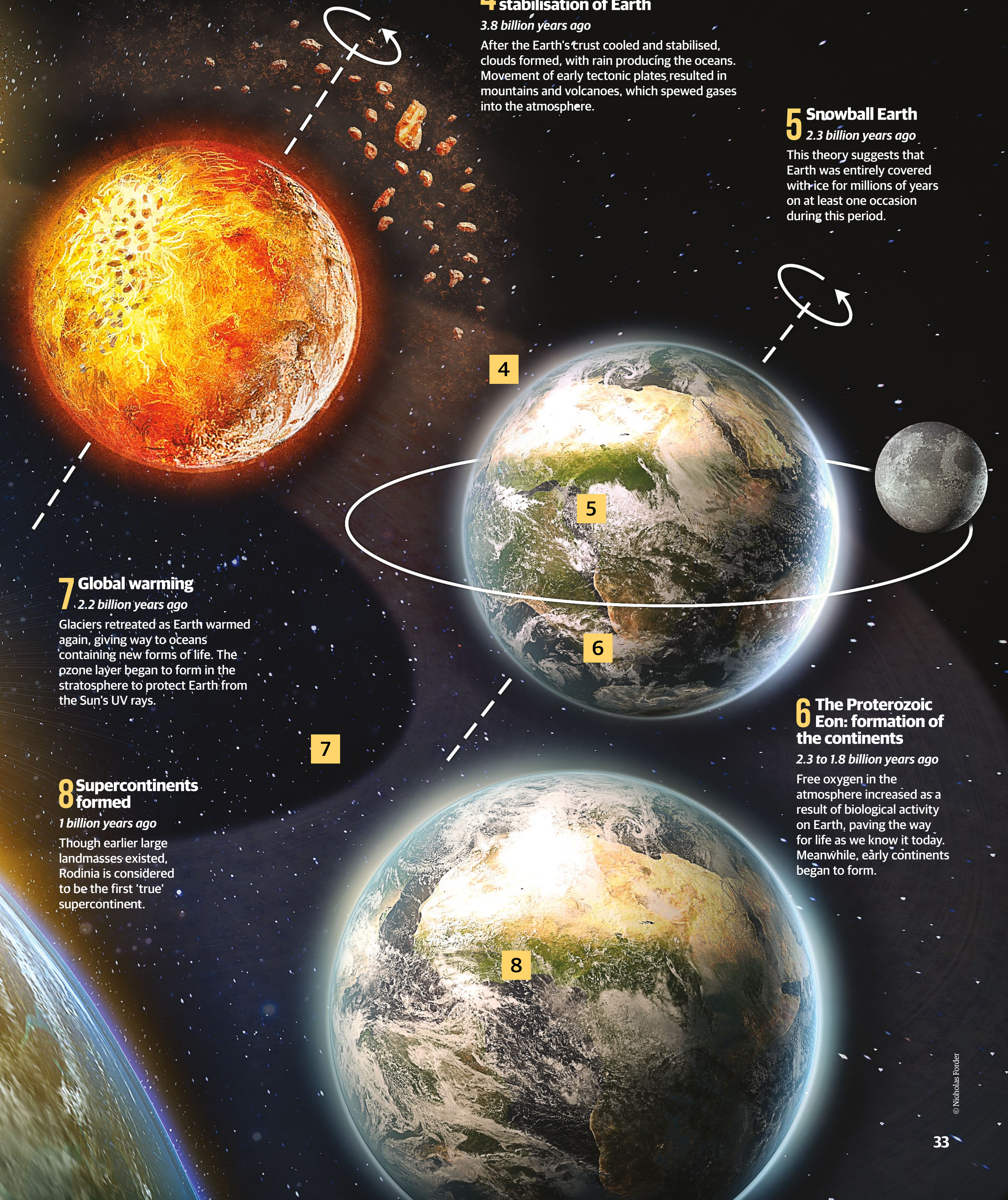
About 300 million years ago

The supercontinent that would eventually split apart to make Laurasia and Gondwana, which then went on to become the seven continents we know today.

10 The Tertiary Period

65 million years ago

The bumping of tectonic plates led to rocks being pushed upwards to form modern mountain ranges such as the Alps and Himalayas.



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4 The Archean Eon: stabilisation of Earth

3.8 billion years ago

After the Earth's crust cooled and stabilised, clouds formed, with rain producing the oceans. Movement of early tectonic plates resulted in mountains and volcanoes, which spewed gases into the atmosphere.

5 Snowball Earth

2.3 billion years ago

This theory suggests that Earth was entirely covered with ice for millions of years on at least one occasion during this period.

6 The Proterozoic Eon: formation of the continents

2.3 to 1.8 billion years ago

Free oxygen in the atmosphere increased as a result of biological activity on Earth, paving the way for life as we know it today. Meanwhile, early continents began to form.

7 Global warming

2.2 billion years ago

Glaciers retreated as Earth warmed again, giving way to oceans containing new forms of life. The ozone layer began to form in the stratosphere to protect Earth from the Sun's UV rays.

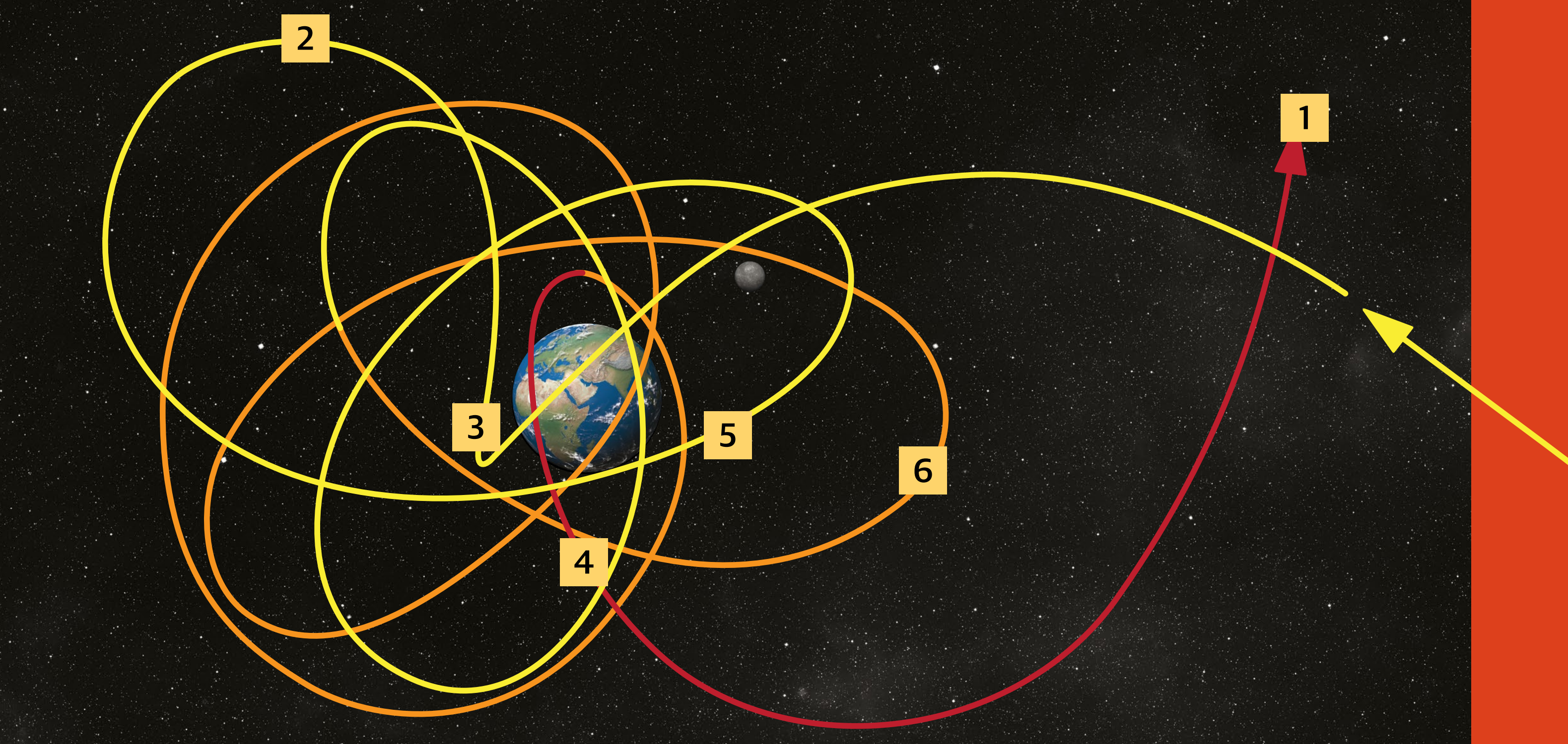
8 Supercontinents formed

1 billion years ago

Though earlier large landmasses existed, Rodinia is considered to be the first 'true' supercontinent.

EARTH'S LITTLE MOONS

Our Solar System's planets have more than one moon – even ours on occasion



1 Temporary visitors
A typical mini-moon will orbit the Earth for around nine months, although some could stay in orbit for decades or more before being recaptured into orbit around the Sun.

2 More than one moon
The Moon isn't our only natural satellite. Asteroids orbiting the Sun can temporarily become mini-moons, following a complex path around Earth.

3 A complex journey
As they are tugged in different directions by the Earth, Moon and Sun, mini-moons follow complicated paths rather than neat elliptical orbits.

4 A confirmed mini-moon
In 2006 the car-sized mini-moon 'RH120' was discovered. It orbited Earth for less than a year before returning to the Sun's more powerful gravity.

5 Tiny satellites
Their small size can make them hard to spot, but experts think there could be a large amount of undetected mini-moons around the Earth.

6 Second satellite
In 2016 NASA's Jet Propulsion Laboratory (JPL) detected a new mini-moon, 469219 Kamo'oalewa. While actually in orbit around the Sun, it appears to circle Earth too.

The authors admit that there are limitations to the new multiple-impact hypothesis, largely that it is based on a limited dataset, making it harder to model possible collisions. "In the current model we explore the implications of moonfalls on the Earth using simulations of the impacts themselves, making use of a hydrodynamical code," explains Perets. "We consider a grid of models for the initial properties of the impact [position of the impact, size of the impacting moon, rotation of the proto-Earth] motivated by the study of dynamics leading to the infalls. This is only one piece in the overall model of the multiple-impacts theory. The main limitations are in direct predictions that can still be observed today billions of years after the fact.

"The general limitation of any Moon model [both single- and multiple-impact models] is that we have only one system to check – we don't have statistics of many moons and their properties. The other limitation is that overall the phase space of possible collisions and impacts is very large, and it is therefore difficult to model any possible type of collision. We only run a grid sampling the huge phase space of possibilities. Nevertheless, there are clear trends that suggest we can generalise our results to a wide range of collisions, so this is not a main obstacle."

If the mini-moons theory is correct and the first continents on Earth really were formed by multiple moonfalls, how exactly would we go about proving this? "The best evidence might be on the Moon," explains Perets. "For example, if we find that the composition on the far side of the Moon is significantly different than that found on the near side, it could be a clear signature of multiple moons making up the current Moon. That being said, finding a small difference – or not – would not exclude it."

Because the Moon is tidally locked to Earth we only ever see its near side, which is where all of

> "THE CURRENT PARADIGM IS INCOMPLETE AND DISCONNECTED FROM THE WIDER PICTURE OF TERRESTRIAL PLANET FORMATION" HAGAI PERETS

the Apollo lunar landings were made. We've seen the far side in photographs and satellite images, which have revealed its heavily cratered surface, but there is yet to have been a NASA mission to this uncharted territory. The China National Space Administration (CNSA), however, has landed a spacecraft on the far side of the Moon as part of the Chinese Lunar Exploration Program. Chang'e 4 touched down on 3 January 2019, achieving a milestone as the first soft landing on the Moon's mysterious far side in the Von Kármán crater. Equipped with a rover, Yutu-2, one of Chang'e 4's main objectives was to study the chemical composition of lunar rock and soil, the first to do so on the far side. A follow-up mission, Chang'e 5, landed on the near side on 1 December 2020, and will further the program's research by returning a sample of lunar rock to Earth for further study.

The idea of impacts leading to the formation of topographic features on planets' surfaces isn't new. The latter stages of planet formation are widely thought to be characterised by extremely violent, catastrophic collisions, and features such as mountains can be seen on planets throughout the Solar System. But some experts disagree that the falling mini-moons would have formed any such features on Earth.

As the Earth took around 100 million years to cool from molten magma into a solid sphere, it is questionable whether mini-moons falling during that time would have left any mark on the molten planet, as any scars left would have been covered. However, the researchers argue that the moonlets would have struck Earth after much of the planet had solidified into a crust and that the impacts would have been gentle enough to remain on the surface, rather than smashing through.

While not yet conclusive, the idea of multiple strikes on Earth producing a series of moonlets which then rained down on Earth is a compelling alternative to the accepted theory. But why is it so important? "The latter stages of accretion, named the giant-impact phase, set the final architecture of the Solar System and the composition of the final planets and their satellites," explains Rufu. "Understanding the formation of the Moon can provide insights on the environment of the early Solar System, and it may help us understand whether satellite formation in general is abundant or whether it requires unique impact conditions.

"Moreover, due to its large size, the Moon stabilises Earth's tilt and provides a somewhat stable climate for life to evolve. If detecting exomoons will be possible in the near future, then it may be more beneficial to look for life around planets with large satellites. Of course, this is somewhat speculative, as we know of only one planet that harbours life, and it happens to have a large satellite."

A better understanding of the impacts that shaped the evolution of Earth could give us vital insights into how life-bearing planets form. In turn, this could help us track down potentially habitable planets in future, and maybe even ensure the endurance of the human race for generations to come. If the mini-moons theory is correct, these moonlets may well have shaped not only our past, but also our distant future.

Libby Plummer

Space science writer

Libby specialises in writing about science. She has contributed to a variety of publications including *Stuff*, *Wired*, *Wareable* and *Metro*.

Right: UCLA researchers Paul Warren, Edward Young and Issaku Kohl with a sample of rock from the Moon

Below: A concept drawing of the early Earth depicts it being battered

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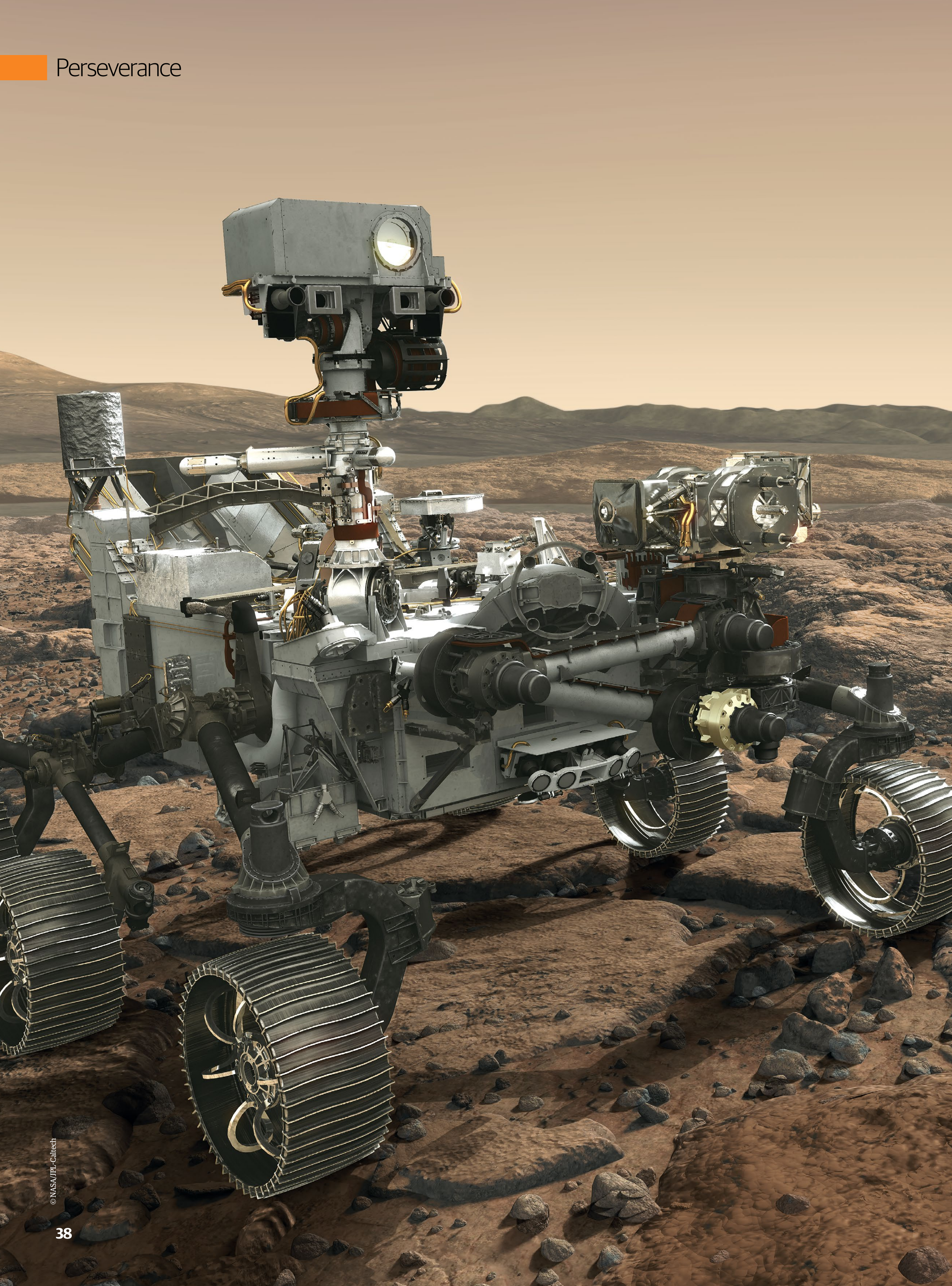

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PERSEVERANCE
NASA'S NEW MISSION TO MARS

The rover that's about to begin a fascinating hunt for life on the Red Planet

Reported by Jonathan O'Callaghan

For decades, we have sent spacecraft to Mars. Our neighbouring planet has held an allure over scientists for a long time, because we think it was once like Earth. Billions or perhaps even just hundreds of millions of years ago, the Red Planet likely had oceans and seas on its surface, providing potential habitats for life. Over time, however, it lost its atmosphere, the water boiled away, and today the surface is a barren, desolate wasteland.

Thanks to numerous missions sent to Mars, however, we know that was not always the case. NASA's Viking 1 and 2 landers, which arrived at the planet in 1976, first looked for signs of life on the surface, with inconclusive results. The Spirit and Opportunity rovers, which arrived in 2004, found evidence for previous wet conditions on Mars. And the Curiosity rover, which landed in 2012 and is still operational today, has painted the most detailed picture yet of how habitable Mars might once have been, having found signs of an ancient streambed and even organic molecules.

Now, a new mission is set to take our search for life on Mars to new heights. NASA's Perseverance rover was launched on 30 July 2020 and is scheduled to touch down on Mars on 18 February 2021. Aesthetically identical to the Curiosity rover but with vastly different instruments on board, the mission is designed with a key goal in mind: to uncover whether life ever existed on Mars. "We're [taking] a big step forward, where we directly seek evidence of ancient life," says Ken Williford from NASA's Jet Propulsion Laboratory (JPL) in California, the deputy project scientist on the Perseverance mission. "Extraordinary claims require extraordinary evidence, and the claim that life once existed on Mars, even though we believe that's likely true, [is extraordinary], and we currently don't have any evidence of it."

The mission - powered by a nuclear battery rather than solar power - begins in earnest in February, when Perseverance lands on Mars. It will use the same landing system employed by Curiosity, known as the 'sky crane', where a rocket-propelled platform will lower the rover to the surface of Mars on a cable before detaching and flying away to safely crash land in the distance. If all goes to plan, the landing should take a total of seven minutes - often referred to as the "seven minutes of terror", as the process itself is entirely autonomous owing to the communications lag caused by the distance between Earth and Mars.

The landing site is a region called Jezero Crater, a fascinating crater on Mars roughly 45 kilometres (28 miles) across that is thought to be an excellent location to look for signs of past life. Here in the crater scientists think there is an ancient river delta that dates back billions of years that fed water into a lake in the crater. Using its instruments, Perseverance will study this fascinating region for two Earth years (or one Martian year) after it touches down, with the very likely possibility of an extended mission beyond this.

After landing, Perseverance will begin getting itself ready to perform this search for life. "The first thing we're going to do is really assess the health of the vehicle," says Matt Wallace from JPL, the deputy project manager on the mission.

THE AIMS OF MARS 2020

Was there life on Mars?

Mission involved: Perseverance

The main goal of the rover is to look for evidence of past microbial life on the surface of Mars.

What was the climate like?

Mission involved: Perseverance

The rover will help scientists piece together what the climate on Mars used to be like and whether it supported life.

Can we fly on another planet?

Mission involved: Ingenuity

This 'Mars helicopter' will attempt to fly on Mars using its propellers. If it's successful future human missions could also use such flying drones.

What is the geology of Mars?

Mission involved: Perseverance

The rover will study rocks inside Jezero Crater to try and work out how the Martian crust and surface has changed over time.

Can humans live on Mars?

Mission involved: Perseverance

By producing oxygen on Mars and looking for subsurface ice, the rover will help us decide how future human missions might work.

MEET PERSEVERANCE AND INGENUITY

Here's how the rover and drone will operate on the surface of Mars

1 Mastcam-Z

Used for: Imaging Mars

Operated by: Arizona State University

Located on top of the rover's 'mast', this camera system will take high-definition videos and images of Mars, including images in 3D.

2 Mars Environmental Dynamics Analyzer (MEDA)

Used for: Weather monitoring

Operated by: National Institute for Aerospace Technology, Spain

This instrument will measure the Martian weather, including wind speed, temperature, humidity and even dust particles in the surrounding atmosphere.

3 Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE)

Used for: Making oxygen

Operated by: Massachusetts Institute of Technology

MOXIE will take carbon dioxide out of the Martian atmosphere and see if it can turn it into oxygen, which could be useful for future human missions.

4 Planetary Instrument for X-ray Lithochemistry (PIXL)

Used for: Looking for life

Operated by: NASA

This X-ray instrument will study the chemical composition of rocks and look at features as small as a grain of salt in the search for microbial life.

5 Radar Imager for Mars' Subsurface Experiment (RIMFAX)

Used for: Looking underground

Operated by: University of Oslo

This instrument will use its radar to look more than ten metres (30 feet) under the surface of Mars for signs of water and ice.

6 Scanning Habitable Environments with Raman & Luminescence for Organics & Chemicals (SHERLOC)

Used for: Looking for life

Operated by: NASA

SHERLOC will use ultraviolet light to look for organic chemicals. It even includes a tiny Martian meteorite and pieces of spacesuit material to calibrate itself.

7 SuperCam

Used for: Studying rocks

Operated by: Los Alamos National Laboratory, New Mexico

SuperCam will use a laser to study rocks from more than seven metres (23 feet) away, looking for ones that could have preserved signs of microbial life.

8 Ingenuity's blades

Used for: Flying on Mars

Operated by: NASA

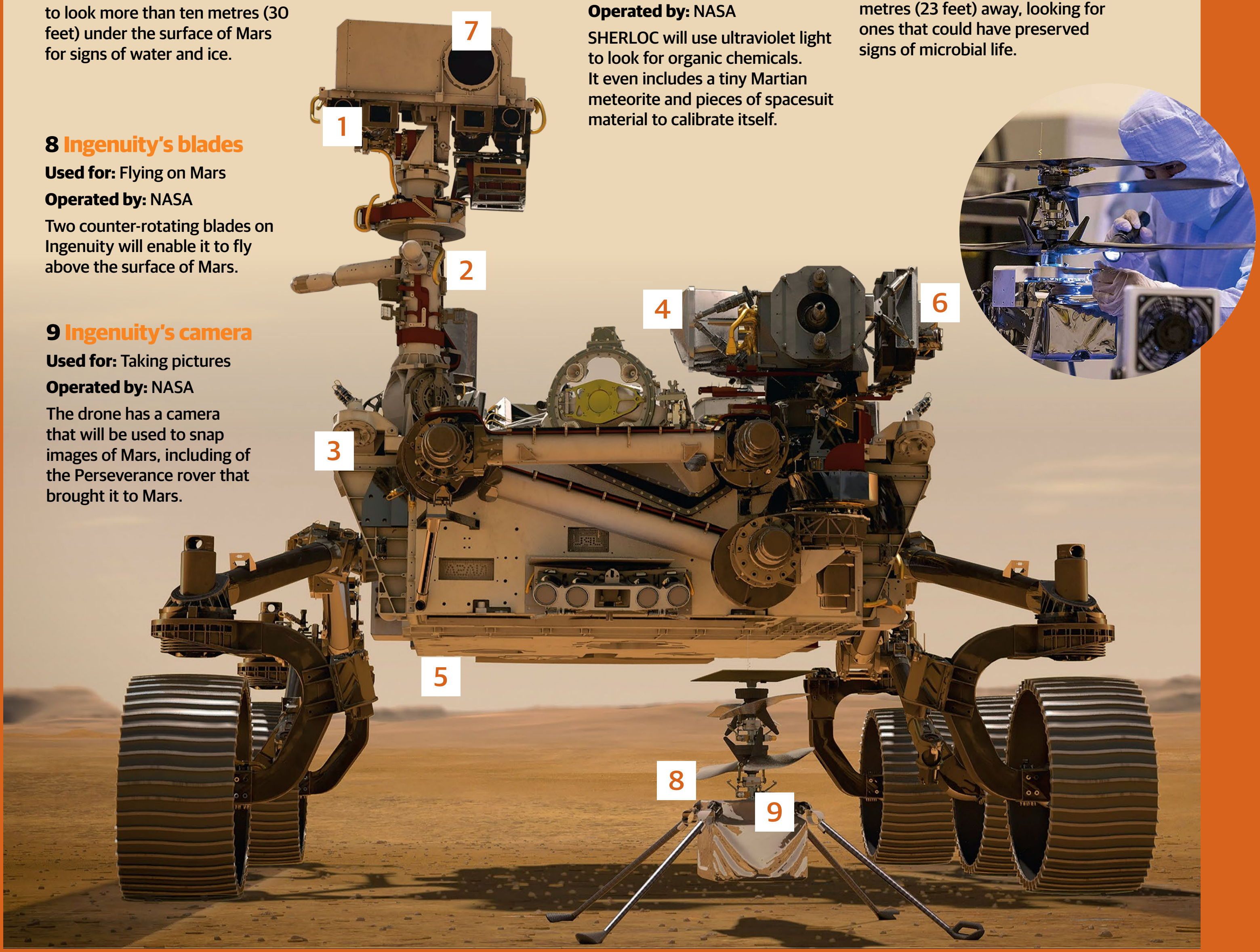
Two counter-rotating blades on Ingenuity will enable it to fly above the surface of Mars.

9 Ingenuity's camera

Used for: Taking pictures

Operated by: NASA

The drone has a camera that will be used to snap images of Mars, including of the Perseverance rover that brought it to Mars.



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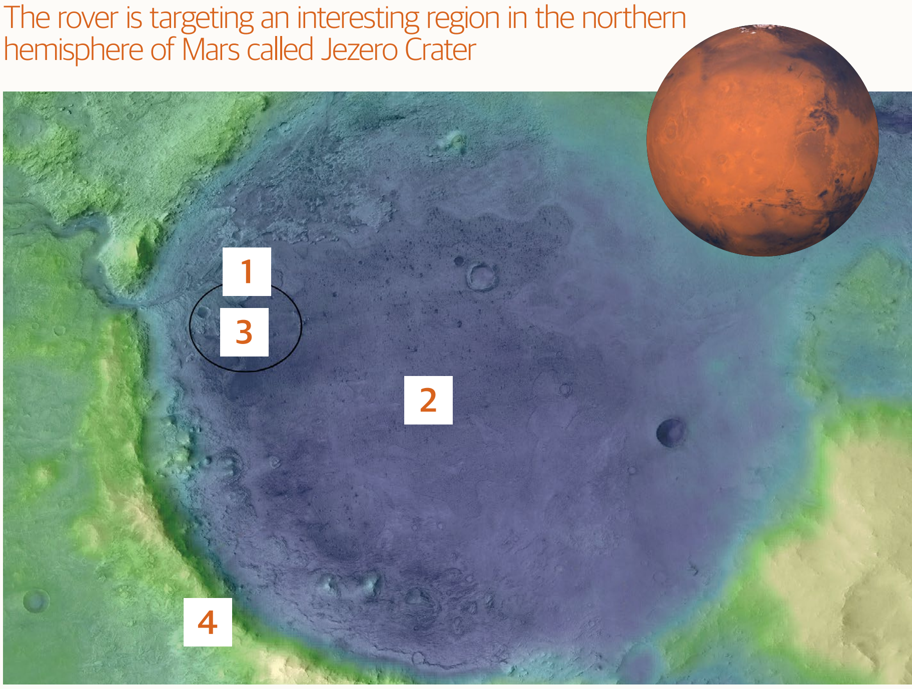
WHERE PERSEVERANCE WILL LAND

The rover is targeting an interesting region in the northern hemisphere of Mars called Jezero Crater



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1. Landing ellipse

Perseverance's autonomous landing system will target a landing area that is about eight kilometres (five miles) across.

2. River delta

The rover will explore what looks to be an ancient river delta inside the crater, which scientists think may be billions of years old.

3. Lakebed

The ancient river is thought to have fed a lake inside the Jezero Crater, where life may have once resided.

4. Midway

After finishing its main mission in Jezero, Perseverance could drive out of the crater to another interesting location called Midway.

"Then we'll start to assess our landing site and take pictures. We'll figure out where exactly in Jezero we are and look for any immediate hazards." The rover is currently targeting a landing area about eight kilometres (five miles) across, but it's not certain where within this area the rover will land.

The landing itself will include video footage taken from on board the spacecraft. "This will be the first time that we'll have that kind of video of a spacecraft landing on another planet," says Wallace. "We expect that to be very exciting". Providing everything has gone to plan, and all its instruments are in operational order - such as the rover's robotic arm to pick up and study samples - the early phase of the mission can begin.

That phase, before the main science mission of the rover starts, includes an exciting experiment. Perseverance will deploy a small flying drone on Mars called Ingenuity, which will aim to use its rotors to fly above the surface - the first attempt at aerial flight on another world. Designed to fly up to distances of 300 metres (984 feet) on flights lasting 90 seconds, Ingenuity is largely a technology demonstration mission to practise flying on other worlds, but it will also take images of the surface from the Martian air.

Ingenuity is expected to fly at some point in the first 90 days of the mission. Beyond that, the crux of the mission can begin. "The science team has some preliminary thoughts about where they'd like to go," says Wallace. "The delta, of course, as well as the lakebed. Those are places where water clearly existed and there would have been sediment - places on Earth that you would look for signs of life." Searches will also include looking at deposits in the lakebed itself, such as mudstones, along with minerals known as carbonates that might have formed at the shoreline of the lake.

Perseverance will look for biosignatures with a variety of its seven onboard instruments. This will include looking for microfossils - essentially fossilised microbes within Martian rocks themselves. "By biosignatures we really mean fossilised cells from micro-organisms," says planetary geologist Frances Rivera-Hernandez from Dartmouth College in New Hampshire. "We're looking for evidence of fossilised micro-organisms." The rover will be able to measure the composition of such targets, as well as taking images, with its onboard instruments - getting us closer than ever before to finding life on Mars if it's there.

Crucially, however, the rover is not designed to analyse some of the most intriguing samples it finds alone. Instead, it will collect and store them within caches - essentially small tubes - that it will leave on the Martian surface. At some point later this decade, a joint sample return mission from NASA and the European Space Agency (ESA) will launch to Mars, pick up the samples and return them to Earth. "A sample return lander and orbiter could launch as early as 2026," says Williford. The lander would include a small rover that would pick up the caches and bring them back to a rocket that would launch back to the orbiter, which would then return to Earth by 2031 at the earliest.

While many aspects of those missions have yet to be finalised, the overriding goal of returning them to Earth will remain the same - whether life really did, or still does, exist on Mars. "You really can't confirm biosignatures until you bring the samples back to Earth," says Rivera-Hernandez. "It's going to be amazing, because the only samples we have from Mars are Martian meteorites. This time we'll actually be able to select samples from Mars that we think would have these biosignatures."

Searching for life is not the rover's only goal, however. Also on board is an instrument called MOXIE that will practise producing oxygen from carbon dioxide in the Martian atmosphere. This could be a crucial tool for human missions to Mars, allowing them to produce their own oxygen on the Red Planet. "That molecular oxygen would be useful for astronauts to breathe, but mainly as

Right: The rover launched to Mars on a United Launch Alliance Atlas V rocket from Florida on 30 July 2020

© United Launch Alliance

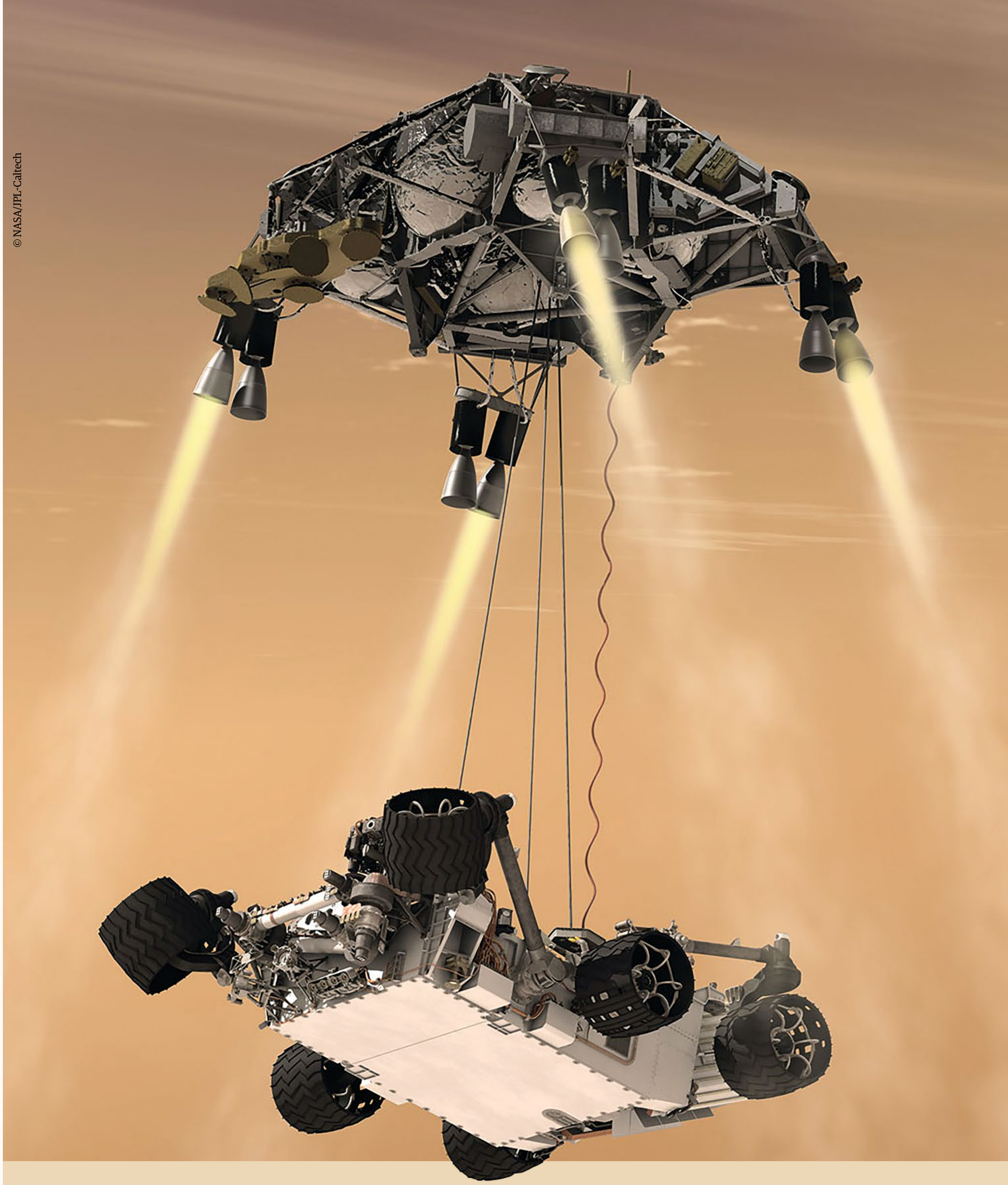
LANDING ON MARS

Matt Wallace, the deputy project manager on the mission, explains what will happen during the landing

What will happen on the day of the landing?
As we get very close, things start happening extremely quickly. About ten minutes prior to landing we will jettison the cruise stage - a piece of the spacecraft that helps us get to Mars - and essentially just be an entry capsule at that point. We will hit the atmosphere at about 21,000 kilometres (13,000 miles) per hour, and we will rapidly go through the series of activities we need to safely put us on the ground.

How will the descent work?
The spacecraft is going to land itself over the course of about seven minutes. It'll hit the atmosphere and roll left and right to guide towards the crater, known as hypersonic navigation. Once it gets to a slow enough speed we'll deploy a 21-metre (69-foot) parachute in a fraction of a second. It's a heart-stopping moment as we wait for verification that it has opened safely. We'll drop our heat shield from the bottom of the capsule, turn on our radar and turn on a new system to start taking pictures of the surface to divert away from hazards.

What happens at touchdown?
We drop out of the backshell, fire up the main engine on our descent stage - which is kind of a jetpack that the rover is attached to - and we'll slow down from 161 kilometres (100 miles) an hour. The rover will deploy down on a tether about seven metres (23 feet) long. Then we cut that tether and the descent stage will throw itself hundreds of metres away, and the rover will be safely on the ground on its wheels.



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Above: The rover will be lowered to the surface by a platform known as the 'sky crane'

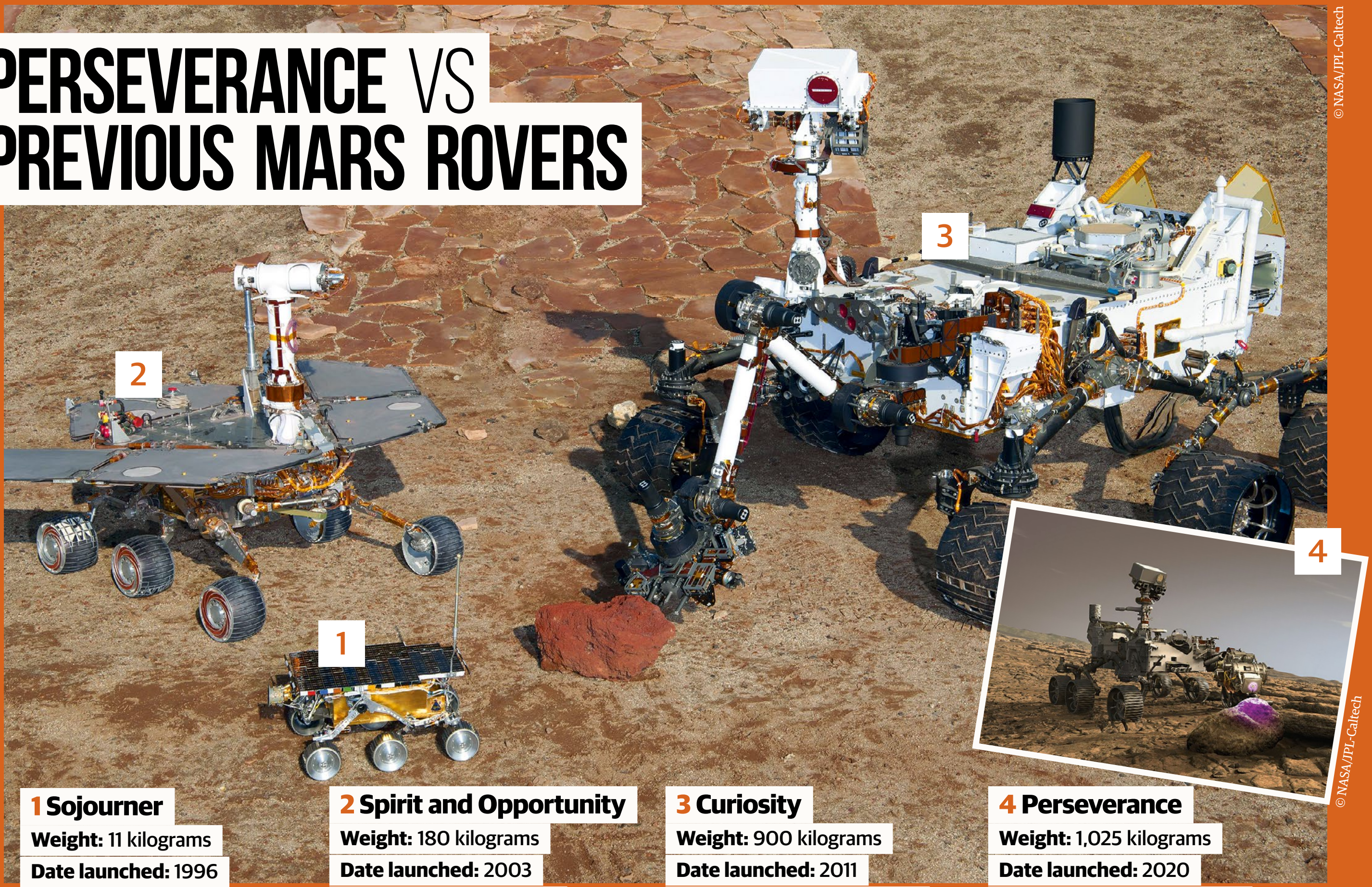
oxygen for their rocket fuel to get them back off the surface and back home," says Williford.

The rover will also take videos on Mars for the first time and return more of the stunning imagery we've come to expect from previous missions like Curiosity. It will do this with a camera system called Mastcam-Z, which has the ability to take panoramic images and zoom in on objects of interest. An instrument called MEDA will produce Martian weather reports - including measuring the temperature, wind speed and humidity at the rover's given location - which could be another useful tool for future human explorers.

A ground-penetrating radar will look for evidence of subsurface water and ice beneath Perseverance, the first time such an instrument will have been sent to Mars. "Being able to see the subsurface stratigraphy [rock layers] is going to be really interesting," says Rivera-Hernandez. "Also trying to see if we can identify ground ice, or just water molecules in general at the landing site, is going to be fascinating." And the rover will also use its cameras to study the surface geology in the region it explores, something that will be of keen interest to geologists. That includes "colours and textures, and the structures of the rocks, and using all of those to reconstruct the environment in which these rocks were laid down," says Williford.

At the end of the rover's two-year primary mission on Mars it's possible Perseverance may be sent to explore another destination. While Jezero Crater is the target for now, the rover could drive out of the crater and to a nearby region called 'Midway' in an extended mission, which also looks like a promising location for signs of life that may have rocks that formed near ancient mineral

PERSEVERANCE VS PREVIOUS MARS ROVERS



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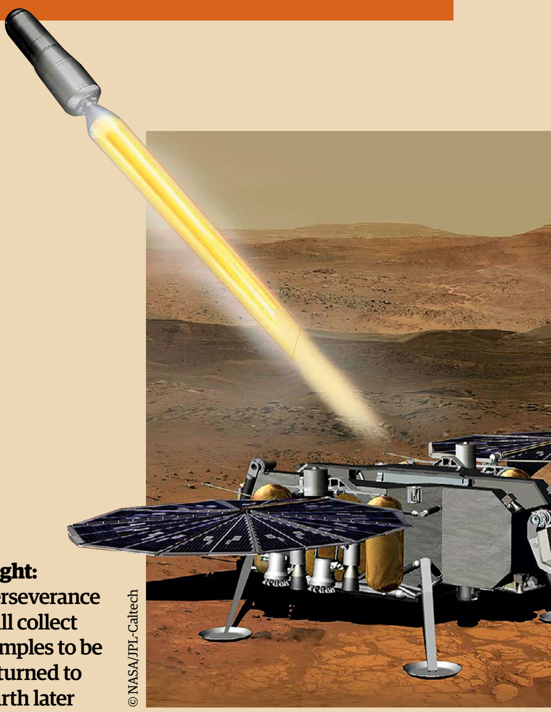
	1 Sojourner	**2 Spirit and Opportunity**	**3 Curiosity**	**4 Perseverance**
Weight:	11 kilograms	180 kilograms	900 kilograms	1,025 kilograms
Date launched:	1996	2003	2011	2020
Size of rover:	65 centimetres (26 inches) long	1.6 metres (5.2 feet) long	Three metres (ten feet) long	Three metres (ten feet) long
Still in operation?:	No	No	Yes	Start date 18 February 2021
Notable achievements:	First rover on Mars. Took hundreds of images	Found evidence of water and past volcanic activity	Found evidence for past habitable Martian environments	N/A

> "WE MIGHT FINALLY KNOW FOR CERTAIN THAT WE ARE NOT ALONE IN THIS UNIVERSE" KEN WILLIFORD

springs on Mars, driven by volcanic activity. "One of the attractive aspects of Jezero is that it's close to some other interesting targets," says Wallace. "There's a good possibility that the science team will be interested in climbing out of Jezero to get to some other interesting sites that are not too far away from the crater itself."

For the time being the focus is very much on Jezero Crater, and if everything goes smoothly, we could be looking at an extremely exciting mission over the next few years. We've managed to work out already that the surface of Mars could have been habitable in the past. Now it's time to find out whether any life did indeed manage to survive here. If it did, we might finally know for certain that we are not alone in this universe. "It's such an enormous question," says Williford. "Absolutely it is our [goal] to search for evidence of ancient life, and we plan to do everything we can to enable that."

Jonathan O'Callaghan
Space and science writer
A journalist based in London, his work regularly appears in the *New York Times, Forbes, Wired, New Scientist* and a variety of other publications.



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Right: Perseverance will collect samples to be returned to Earth later

The story of the stars

We look up today and see the stars divided into the same familiar shapes as our ancestors, but how did the constellations come to be?

Reported by Nikole Robinson

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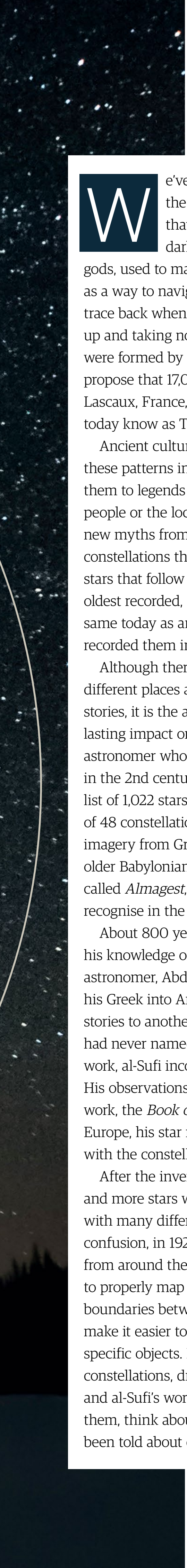


We've always had a fascination with the stars, bright beacons of light that come alive when the sky darkens. They've been revered as gods, used to mark changes in the seasons and as a way to navigate the globe. It's difficult to trace back when exactly people started looking up and taking note of familiar patterns that were formed by these points of light, but some propose that 17,000-year-old cave paintings in Lascaux, France, depict the constellations we today know as Taurus and Orion.

Ancient cultures across the world saw these patterns in different ways, often linking them to legends that were told among their people or the local fauna and flora, or creating new myths from the shapes they saw. The constellations that make up the Zodiac - the stars that follow the ecliptic - are some of the oldest recorded, and remain essentially the same today as ancient Babylonian astronomers recorded them in the 6th century BCE.

Although there are older records from many different places and cultures that tell their own stories, it is the ancient Greeks that made a lasting impact on astronomy. Ptolemy, a Greek astronomer who lived in the city of Alexandria in the 2nd century CE, made a comprehensive list of 1,022 stars, illustrating them as members of 48 constellations, many of which adopted imagery from Greek myths and legends and older Babylonian ideas. This ancient text, called *Almagest*, became the basis of what we recognise in the sky today.

About 800 years after Ptomely recorded his knowledge of the heavens, a Persian astronomer, Abd al-Rahman al-Sufi, translated his Greek into Arabic, bringing his stellar stories to another part of the globe. As Ptolemy had never named the individual stars in his work, al-Sufi incorporated Arabic names. His observations were so advanced that his work, the *Book of Fixed Stars*, travelled across Europe, his star names being accepted along with the constellations they were woven into.

After the invention of the telescope, more and more stars were discovered and named, with many different influences. To avoid confusion, in 1922 a group of astronomers from around the world decided it was time to properly map the stars, putting official boundaries between the constellations to make it easier to navigate the sky and locate specific objects. Now divided into 88 official constellations, drawing heavily from Ptomely and al-Sufi's works, next time you gaze up at them, think about the many stories that have been told about each one across the ages.

Ancient astronomy

Though the ancient Greek interpretations are the ones that stuck, what did other cultures see in the stars?

Today we know of trillions of stars, and even other galaxies. We have classifications for different stellar types, and can work out a star's mass, density and composition from many light years away. We know that stars are dense balls of gas that are fusing hydrogen to power themselves, creating light as they do. But before the modern age of science, people could only guess at what these bright lights in the night were. Here are some of the oldest interpretations, and what the stars meant to these ancient observers.

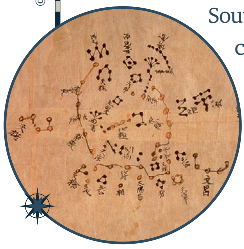
Source: Wikipedia Commons © Jean-Pierre Dalbéra

SIRIUS, THE NILE STAR

Sirius was very important to the ancient Egyptians. Each year in mid-August, it would be the first bright star to rise in the predawn sky, known as a heliacal rising. The timing coincided with the annual flooding of the River Nile, alerting people who lived near its banks that it was time to move inland to safety. A second calendar was created to measure the time until its return. They knew the star as Sopdet, the personification of a goddess associated with the fertility that the flooding brought to the land.

THE FOUR SYMBOLS

Ancient Chinese astronomers charted the night sky into four regions, each of which was assigned one of the Four Symbols: the Azure Dragon of the East, a dragon god; the Black Tortoise of the North, who symbolised longevity; the White Tiger of the West, the king of beasts; and the Vermillion Bird of the South, an elegant fire-red bird. Seven constellations - or 'mansions' - within each of these symbols were used as a way to follow the Moon's motion across the sky, forming an early lunar calendar.



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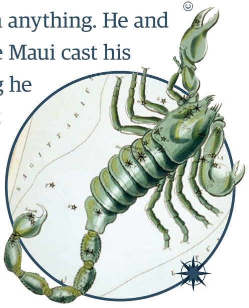
SCORPION OR FISHHOOK?

Part of the Zodiac, this constellation is officially dubbed Scorpius, the Scorpion. But for hundreds of years Polynesians have seen its inverted tail as a fishhook - one belonging to a demigod of legend: Maui. Maui possessed a magical fishhook, Manaiakalani, which could catch anything. He and his brothers set out to sea, where Maui cast his line. Tricking them into thinking he had caught a giant fish, Maui got his brothers to paddle the canoe as fast as they could to reel in his line, pulling up islands from the sea for humans to live on.



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MAYA STAR TRACKING

Mayans were keen astronomers, tracking the Sun, Moon, planets and Milky Way across the heavens and constructing incredibly accurate calendars for the time using their knowledge. They built many structures and buildings to align with certain stars, and there's evidence they had a 13-star Zodiac that took the shapes of the native wildlife. Polaris was also known to the Maya, though they knew it as Xaman Ek. It was sometimes associated with the rain god who brought the storms of winter.

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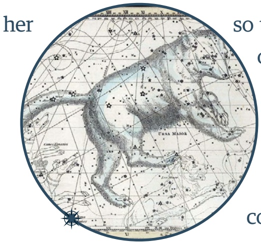
Myths and monsters

How the ancient Greeks wove lasting legends into the sky

Though some constellations were borrowed from the Babylonians - brought to Greece by Eudoxus of Cnidus in the 4th century BCE - ancient Greek scholars considered astronomy to be a mathematic art, a way to use geometry to predict the motion of the heavens. Many ancient Greek scholars mapped and wrote about the stars above and their motions, but the most well known today is Ptolemy's book *Almagest*. In it he identified the 12 constellations of the Zodiac, 21 to the north of the ecliptic and 15 to the south, naming them after heroes and beasts alike from famous poems and myths, whose deeds had allowed them to be made immortal among the stars and revered as semi-divine spirits.

URSA MAJOR (THE GREAT BEAR)

Containing one of the most famous asterisms in the sky and pointing the way to Polaris, Ursa Major had been seen as a bear by many primitive cultures before the ancient Greeks. To the Greeks the bear was Callisto. Zeus had an affair with the huntress, which bore a son. When Zeus' wife found out, she was so enraged that she turned Callisto into a bear. Zeus later placed her in the stars to keep her safe. Callisto is also the namesake of one of Jupiter's moons.



PISCES (THE FISHES)

An equatorial constellation, Pisces forms the shape of two fish connected by a rope of stars. In an effort to escape a monster that had been sent to attack Mount Olympus - the home of the gods - the goddess of love Aphrodite and her son, Eros, transformed themselves into fish in order to flee into the Euphrates River. They tied their tails together with a cord so that they would not lose one another. Its brightest star was originally given the name Kullat Nunu, meaning 'the cord of the fish' due to its place in the constellation.

ORION (THE HUNTER)

Visible in the Northern Hemisphere in the winter months and easily recognised by his famous belt of three bright stars, Orion, the Hunter, has been identified in many cultures over thousands of years as a hunter, shepherd or warrior. In Greek mythology he was the demigod son of Poseidon, and an accomplished hunter. He proudly boasted to the goddess Artemis that he could hunt and kill any creature if he wanted to. This made Gaia, the earth goddess, angry, and she sent a giant scorpion to kill him as punishment for his pride. Orion and Scorpius were both placed in the sky as a warning against arrogance and upsetting Gaia - though on opposite sides of the sky so that they could avoid each other.

> "Orion has been identified in many cultures over thousands of years as a hunter, shepherd or warrior"

HERCULES (THE HERO)

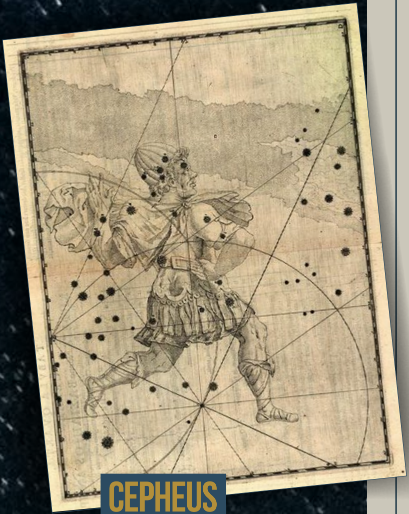
Also known as Heracles and a true icon in ancient Greek mythology, Hercules was perhaps the best-known hero in the stories of old, with tales of his deeds spreading to ancient Rome. A demigod with incredible strength, Hercules was assigned 12 seemingly impossible tasks to atone for a crime he had committed. He used his power, courage and skill to complete all 12 tasks, and was immortalised in the stars as a prize. Many of Hercules' conquests have also been placed among the stars, such as Leo, a fierce lion; Draco, a great dragon; and the Hydra, a sea monster. This constellation is also known for hosting the stunning Great Globular Cluster, Messier 13.

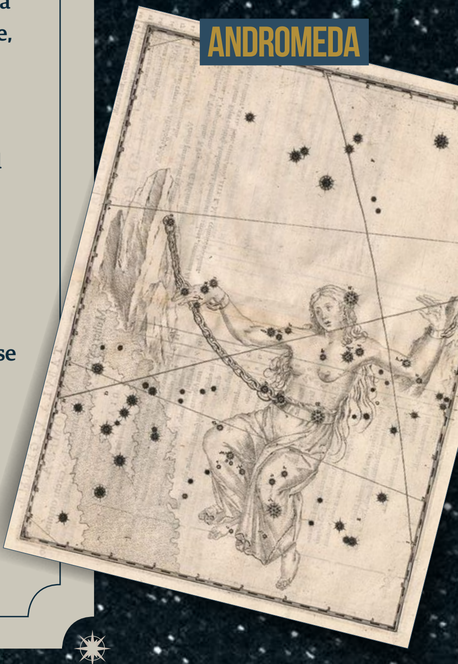
A whole cast of stars

In Greek mythology, Cepheus and Cassiopeia were the king and queen of ancient Ethiopia – now they are the King and Queen in our stars. They had a beautiful daughter, Andromeda. Cassiopeia was incredibly vain, and boasted of her daughter's beauty, telling people she was lovelier than even the Nereids, sea nymphs whose beauty was renowned. This vanity angered the Nereids, who complained to the sea god Poseidon about the vain queen's words. To punish the queen for her arrogance, Poseidon sent floods and a sea monster, Cetus – though this constellation is often called the Whale in astronomy – to terrorise the coast of Ethiopia.

Wanting to appease the gods and end Poseidon's wrath, the king and queen were told that they must sacrifice their daughter to the sea monster. They chained the beautiful maiden to a rock to await her fate – hence why the constellation of Andromeda is often called 'the Chained Maiden' in modern times. As luck would have it, the great hero Perseus was flying back over Ethiopia on his winged horse, Pegasus, after slaying the Gorgon Medusa. Falling in love at first sight with the beautiful damsel in distress below, Perseus saved her from her doom using the severed head of Medusa as a weapon, and took Andromeda as his bride. All of these characters have been placed into the stars, with the majority of them grouped together in a section of sky in the Northern Hemisphere, while Cetus lurks further south.

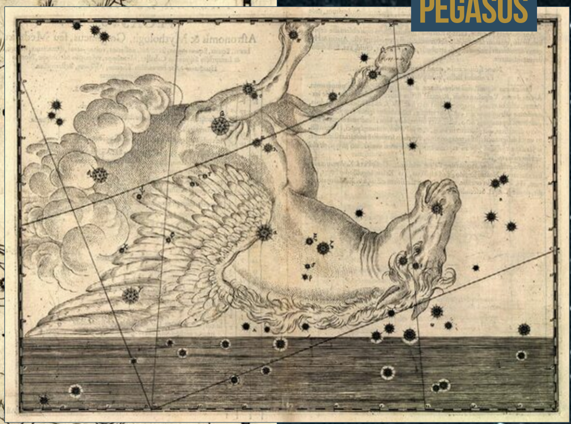
When the stars were later given names by al-Sufi, the variable star Beta Persei was named Algol, meaning the Demon's Head. It is said to depict the eye of the severed head of Medusa in the constellation of Perseus – although gazing up at this particular star won't turn you to stone.


CEPHEUS


ANDROMEDA

CASSIOPEIA

PERSEUS


PEGASUS

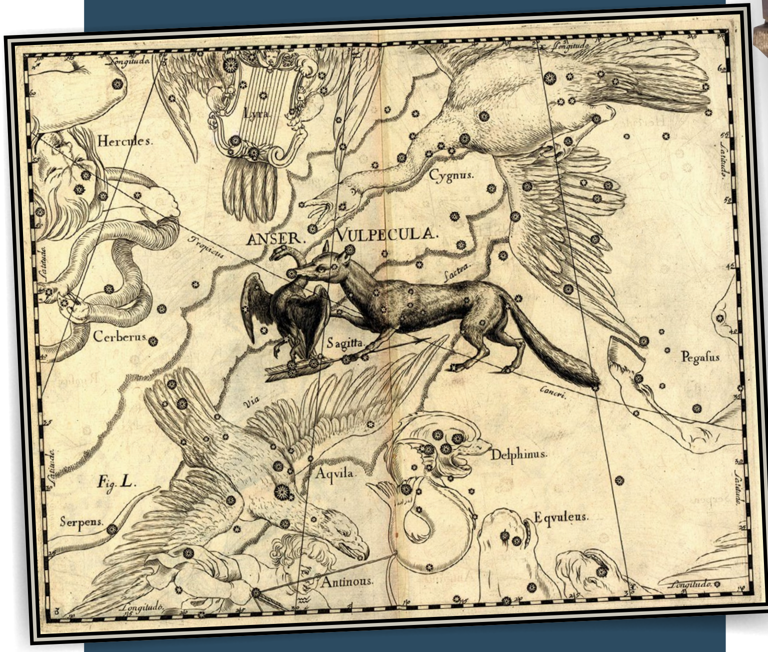
CETUS

x10 images © Alamy

Uncovering the southern skies

How the Age of Exploration discovered new groups of stars to give meaning to

The majority of the ancient constellations lie in the Northern Hemisphere because that is what the ancient cultures that mapped them could see from their positions on Earth. When European explorers began to sail further south to investigate new parts of the sea for potential trade routes in the 1600s, they found that the star maps they used for navigation were lacking the further they went. They soon realised that the skies below the equator contained uncharted stars that formed new patterns above them. Astronomers set out to map the entirety of the sky, classifying these newfound stars into constellations. Some of these built upon the legends of the northern constellations, while others were based on tools that helped in astronomy and navigation or exciting new animals that had been discovered as new continents were conquered.



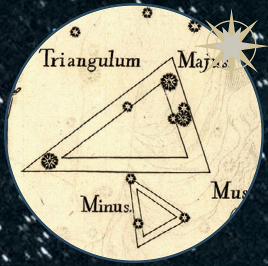
VULPECULA (THE LITTLE FOX)

Sitting in the sky in the middle of the Summer Triangle, Vulpecula, Latin for 'little fox', was originally envisioned as a fox with a goose clamped in its jaws by Johannes Hevelius, with him dubbing it Vulpecula et Anser – the little fox and the goose. Though he didn't see these two animals as separate constellations, the stars were later divided as such. Since then they have been merged into one constellation again, though the goose is remembered in the name of Vulpecula's brightest star, called Anser.

x9 images © Alamy

TRIANGULUM AUSTRALE (THE SOUTHERN TRIANGLE)

Not to be confused with its northern counterpart Triangulum, the Southern Triangle moved around the sky a little before it ended up where we find it today. The earliest depiction was by Dutch astronomer Petrus Plancius in 1589 on a celestial globe, though he incorrectly placed the tiny triangle to the south of the much larger constellation of Argo Navis. Plancius also originally listed the constellation as Triangulus Antarcticus. The German astronomer Johann Bayer later correctly depicted the constellation in his star atlas *Uranometria* in 1603, where it was given its current name of Triangulum Australe.



SCUTUM (THE SHIELD)

A long, narrow diamond of stars lying close to the ecliptic, Scutum was first classified by Polish astronomer Johannes Hevelius in 1684. He originally named it Scutum Sobiescianum – Shield of Sobieski – after King John III Sobieski to commemorate his victory in the 1683 Battle of Vienna. The king is also said to have helped Hevelius rebuild his observatory after a terrible fire almost destroyed it in 1679. The name was later shortened, like so many names of constellations have been over the years, to make it easier to reference. Scutum depicts a specific type of curved, oblong-shaped shield that was used in ancient Rome.

COLUMBA (THE DOVE)

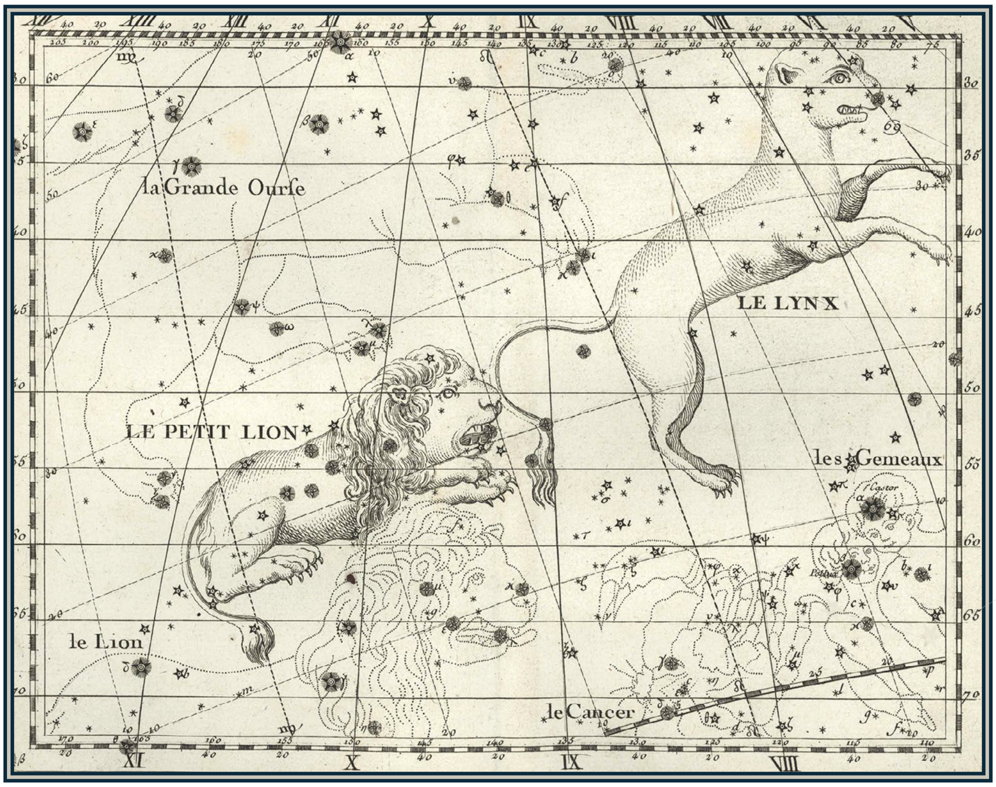
A small winter constellation in the Southern Hemisphere, Columba, the Dove, was first depicted on a planisphere by Petrus Plancius in 1592, where he listed the stars as Columba Noachi – Noah's Dove. Not the only constellation to be named after a symbol of Christianity, the dove in the story of Noah's Ark was sent out to search for signs of land after the great flood. Returning with an olive branch in its beak, doves became a symbol of hope and peace. The constellation is often drawn carrying this branch in its beak. Its brightest star is Phact, which derives from an Arabic word for 'ring dove'.

TELESCOPIUM (THE TELESCOPE)

Although humans had explored the stars for many years by the time telescopes came to use, as their use spread, astronomers could see more stars than ever before. The invention - which can be traced back to a patent by the Dutch spectacle maker Hans Lippershey in 1608 - was truly a revolution in observing the heavens. It's no wonder that astronomers decided to honour the invention with a place among the stars. French astronomer Nicolas-Louis de Lacaille first introduced it as a constellation in around 1751 after observing and cataloguing 10,000 southern stars and forming 14 new constellations.

LEO MINOR (THE LITTLE LION)

One of the smallest constellations in the entire sky, Leo Minor was assigned its leonine image in the 1600s by astronomer pair Elisabeth and Johannes Hevelius to fill a dark patch in the sky that Ptolemy had found unremarkable. This constellation neighbours Leo, so is often depicted as a lion cub - the name translates from Latin as 'little lion'. The pattern of stars that makes up Leo Minor is very similar in shape to a northern constellation, Delphinus, the Dolphin. Both are diamond shapes with a tail, looking a little bit like kites, but the two are not related at all in their naming or story.



MUSCA (THE FLY)

Though for around 200 years this constellation had a second name - Apis, the Bee - Dutch astronomer Petrus Plancius originally named it De Vlieghe, Dutch for the Fly, when he established 12 new southern constellations based on observations by Dutch explorers who had sailed on a trading expedition and noted the new patterns above them. It is the only constellation to be named for an insect. Due to its closeness to Chamaeleon - named after the reptile first encountered by explorers of the time - they are often depicted together, with the Chameleon trying to snack on the Fly.

© Getty

GALEX SOLVES BLUE RING NEBULA MYSTERY

A stellar collision is the culprit behind the strange ultraviolet phenomenon

Scientists have uncovered new evidence in the mysterious fluorescent debris of the Blue Ring Nebula that may explain how the strange structure formed. The nebula harbours a central star, TYC 2597-735-1. An unusual ultraviolet ring surrounds the star, which astronomers first observed in 2004 using NASA's now-defunct Galaxy Evolution Explorer (GALEX).

The formation of this peculiar ring - which is actually invisible ultraviolet light that has been colour-coded blue in the telescope images - has largely remained a mystery. "Every time we thought we had this thing figured out, something would tell us, 'No, that's not right,'" said Mark Seibert, an astrophysicist with the Carnegie Institution for Science.

Using the W. M. Keck Observatory in Hawaii, researchers found that the blue ring is actually the base of a cone-shaped cloud of glowing molecular hydrogen that extends away from the central star towards Earth. The new observations also show a second cone-shaped cloud that extends from the star in the opposite direction. The bases of the cone-shaped clouds appear to overlap when viewed from Earth, creating the ring shape around the star, said Christopher Martin, a physicist at the California Institute of Technology (Caltech) and former principal investigator of GALEX.

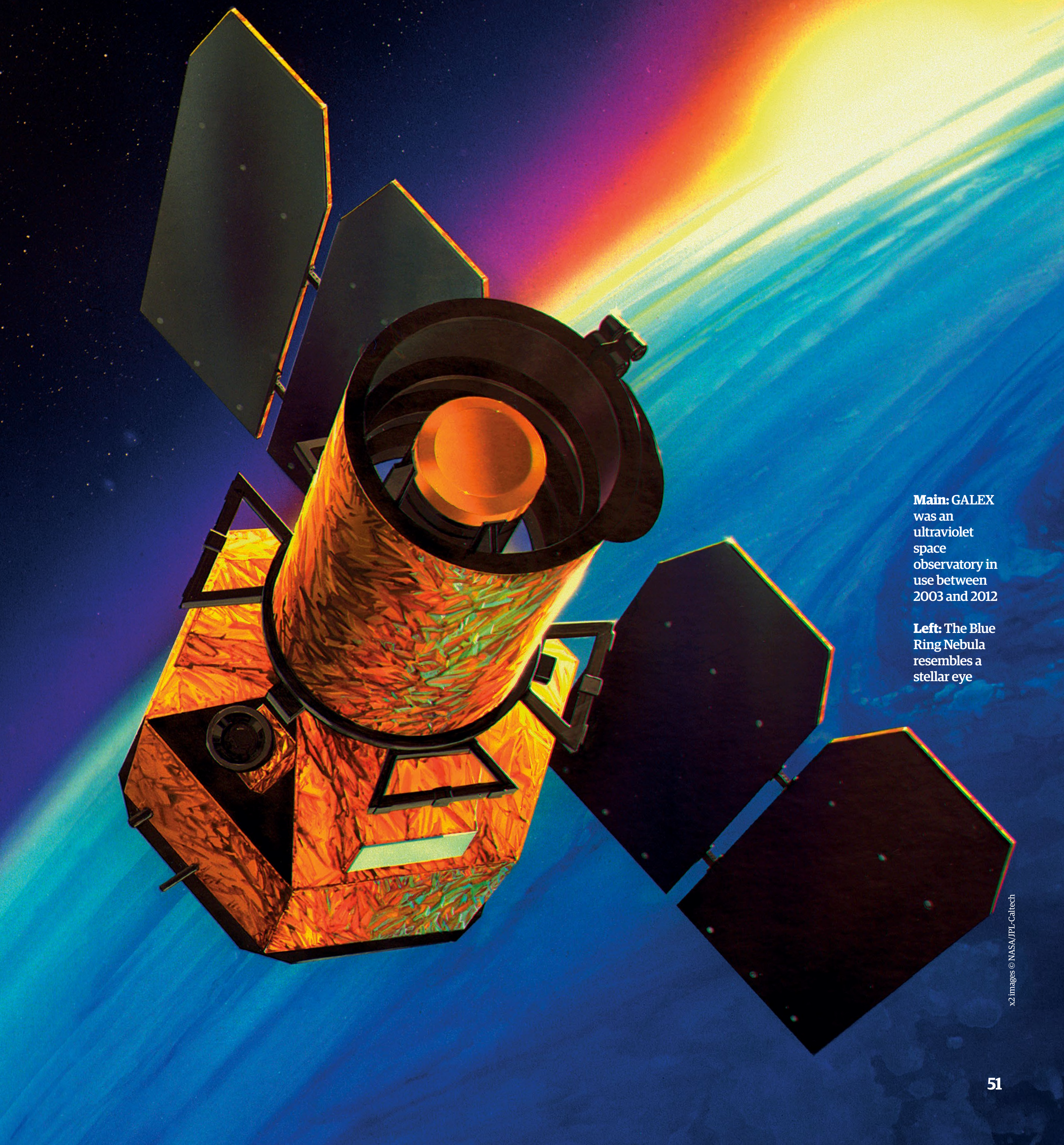
The scientists behind the new research believe that the clouds of fluorescent debris formed after a Sun-like star collided with and consumed a smaller stellar companion only a few thousand years ago. The recent observations capture a never-before-seen evolutionary phase of a stellar collision. "The merging of two stars is fairly common, but they quickly become obscured by lots of dust as the ejecta from them expands and cools in space, which means we can't see what has actually happened," said Keri Hoadley, a physicist at Caltech.

The timing of the new observations was critical in helping scientists understand the phenomenon. "It's like catching sight of a baby when it first walks," said Don Neill, an astrophysicist at Caltech and a GALEX team member. "If you blink, you might miss it."

It was that timing that let the researchers really see what was going on. "We think this object represents a late stage of these transient events, when the dust finally clears and we have a good view," said Hoadley. "But we also caught the process before it was too far along; after time the nebula will dissolve into the interstellar medium, and we would not be able to tell anything happened at all." The stellar collision ejected a cloud of hot debris into space. As the debris flew outward, it created a shock wave that heated up hydrogen molecules in the debris cloud, producing the ultraviolet emissions scientists first observed back in 2004.

The researchers also used archived data from NASA's Spitzer Space Telescope and the Wide-field Survey Explorer (WISE), both of which revealed an excess of infrared emissions around the central star of the Blue Ring Nebula. These observations suggest that the star is surrounded by a disc of dust that absorbs the star's light and then reradiates in the infrared. The researchers believe that this disc cut the debris cloud surrounding the star in half, creating the two cone-shaped clouds that extend in opposite directions from the star.

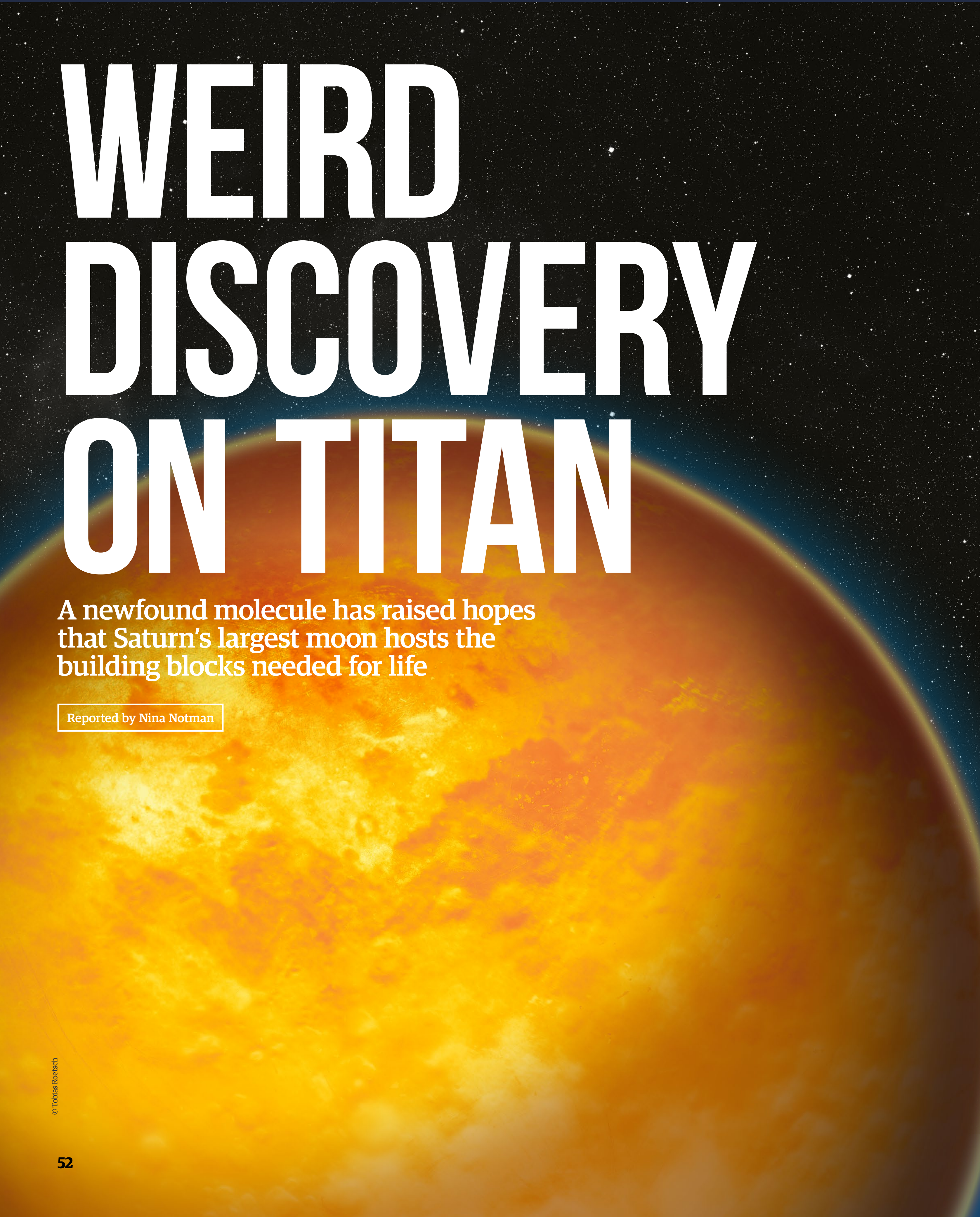
> "RESEARCHERS FOUND THAT THE BLUE RING IS ACTUALLY THE BASE OF A CONE-SHAPED CLOUD OF GLOWING MOLECULAR HYDROGEN"



Main: GALEX was an ultraviolet space observatory in use between 2003 and 2012

Left: The Blue Ring Nebula resembles a stellar eye

x2 images © NASA/JPL-Caltech



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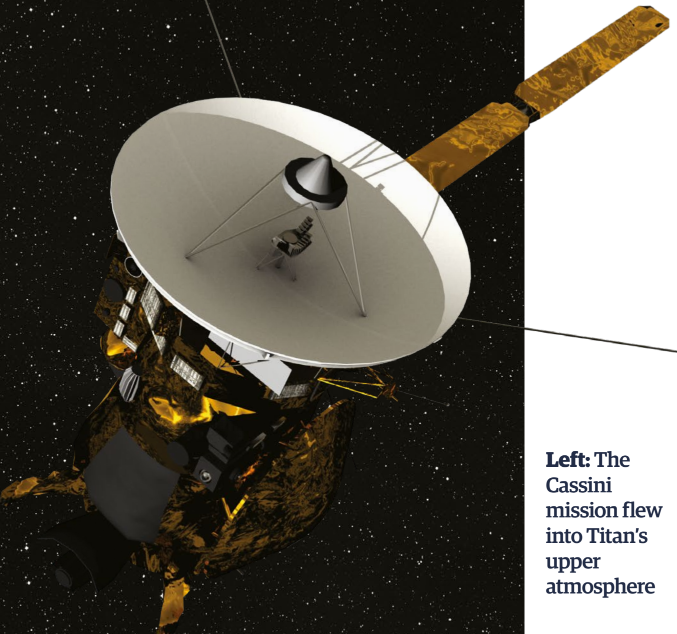
WEIRD DISCOVERY ON TITAN

A newfound molecule has raised hopes that Saturn's largest moon hosts the building blocks needed for life

Reported by Nina Notman



Left: The Cassini mission flew into Titan's upper atmosphere

Are we alone in the universe? Humanity has been pondering the answer to this question for many years now, but no evidence has been found that we aren't - at least not yet. But it's not for lack of trying. Recent decades have seen us employ increasingly sophisticated telescopes and space missions in the search for alien life. We use tools able to listen out for radio and light messages that may be being sent from intelligent life forms. And other instruments are able to hunt celestial bodies, in our Solar System and beyond, for molecules that could potentially indicate the presence of any plant or animal life.

Saturn's largest moon, Titan, is an enticing location for molecule hunters. Both telescope measurements and space missions, most recently Cassini, have found that its atmosphere and surface are a treasure trove of organic molecules. These chemical compounds, composed of both carbon and hydrogen, form the basic building blocks of all living things on Earth. "We are looking for the LEGO blocks that you could use to build up more complex molecules," explains astronomer Conor Nixon from NASA's Goddard Space Flight Center.

Cyclopropenylidene is one such small organic molecule recently spotted by Nixon's crack team of molecule hunters. This finding was published in a paper in the *Astronomical Journal*. The finding of cyclopropenylidene is particularly exciting because it's the second structure with a closed loop to be found in this locality. The first was the six-membered ring benzene in 2003. Closed loops are exciting finds because the nucleobases - the A, C, T and G - which make up the rungs of the ladder in our own DNA molecules are themselves six-member rings. DNA is the code of life; it contains the instructions for the development and function of all living things.

Cyclopropenylidene is a triangle containing three carbon atoms and two hydrogen atoms. "It might be a lower level ingredient that you can use to build up these larger ring molecules," explains Nixon. "Finding it takes us a little bit closer to deciphering the organic chemistry that can lead to these larger, more complex things that could be even more life-like down the road."

> “IT TAKES US A LITTLE BIT CLOSER TO DECIPHERING THE ORGANIC CHEMISTRY THAT CAN LEAD TO MORE COMPLEX THINGS” CONOR NIXON

Titan is similar to Earth in more ways than just hosting an abundance of organic molecules. It has a landscape that visually resembles ours, with plains and dunes, liquid rivers, lakes and seas, and a weather cycle with clouds and rain. There are also some notable differences. It is mind-numbingly cold, with a peak summer temperature of around -180 degrees Celsius (-292 degrees Fahrenheit). The atmosphere contains no oxygen and the surface liquid is a mixture of the hydrocarbons methane and ethane. The rain on Titan is also methane rather than water.

If Titan's surface harbours life, its lakes have been pinpointed by some as the most likely location. But surface life on Titan can't be life as we know it. It would be an exotic type of methane-based life that has been hypothesised to possibly breathe in hydrogen, rather than oxygen, and exhale methane, rather than carbon dioxide.

Finding life as we know it hasn't been ruled out for Titan though. There is strong evidence that large oceans of liquid water are sloshing around beneath its crust. These, astrobiologists suggest,

TITAN'S WEIRD MOLECULE

Cyclopropenylidene's presence in this location was highly unexpected

It's a triangle

Cyclopropenylidene is a triangle of three carbon atoms with two hydrogen atoms hanging off it. Closed loops are important structures in the search for life.

It's super friendly

Because of its triangular structure, cyclopropenylidene is highly unstable. It therefore seeks to join up with other molecules to form more stable structures.

It's hard to spot

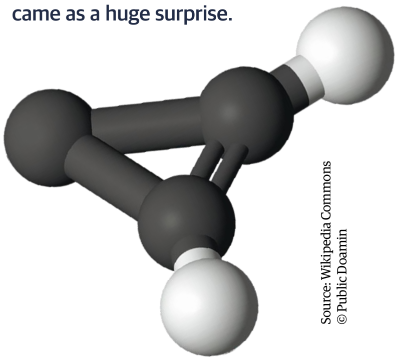
On Earth, cyclopropenylidene has never been seen out in the wild. It has, however, been produced in a laboratory.

It likes the cold

Cyclopropenylidene has been observed in the galaxy using radio telescopes. It frequents the extremely cold clouds of gas and dust that float between star systems.

Found on Titan

Cyclopropenylidene has only been observed in one atmosphere: Titan's. Its presence in the relative warmth of this spot came as a huge surprise.



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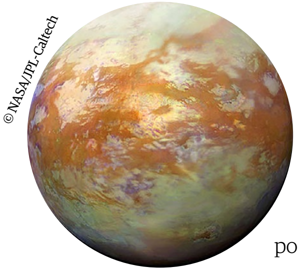
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may contain life in a much more recognisable form.

Alien life hunters keep an open mind to both possibilities: life as we know it and life as we don't. Either way, organic molecules are expected to be needed. Titan's outer atmosphere – where the cyclopropenylidene was found – is a location well known to have lots of chemistry going. "It's like a chemical factory," says Rosaly Lopes, a Titan expert at NASA's Jet Propulsion Laboratory (JPL).

Titan's atmosphere contains approximately 95 per cent nitrogen and five per cent methane. In the outer edges of the atmosphere, exposure to energy from the Sun and energetic particles in Saturn's magnetosphere drive reactions between the gases, generating a 'soup' of progressively more complex molecules.

A ground-based telescope array positioned high up in the Chilean Andes is a popular tool for hunting down these molecules. The Atacama Large Millimeter/submillimeter Array, better known as ALMA, is a radio telescope, meaning it looks at radio waves being given off by objects in space. This section of the electromagnetic spectrum is well known for holding the secrets of some of the coldest objects in the universe. "ALMA came online in 2011 and is a very powerful telescope that has been revolutionising our studies," says Nixon.

Atmospheric hunts such as Nixon's typically start out with predictions of organic molecules that might be hanging out there. Conjectures consider other molecules known to be in that location, the temperature of the area and how far apart the molecules all are from each other. Next, time on ALMA is negotiated. For some telescopes, such as Mauna Kea in Hawaii, astronomers go to the telescope and assist with their data collection. This isn't the case with ALMA. "We don't go and babysit the telescope; it's far too big and complex. Data is collected by specialist engineers who know exactly what they're doing," Nixon says.

Once collected, the data is searched for evidence of any of the predicted organic molecules. It's possible to positively identify molecules because every molecule produces a unique pattern in the electromagnetic spectrum. These so-called

WHAT HAPPENS ON TITAN'S SURFACE?

1. Nitrogen & methane leave the surface

These two gases percolate up from the surface of Titan, eventually reaching its outer atmosphere.

2. The gases combine

Once in the outer atmosphere, the nitrogen and methane react to form small organic molecules such as cyclopropenylidene.

3.They react again

These organic molecules then grow larger by reacting with each other, and also other nitrogen and methane.

4. Again and again

These reactions keep happening, producing a soup of different organic molecules.

5. The molecules sink

The heavier molecules then sink towards the surface, clumping together as they do so.

6. On the surface

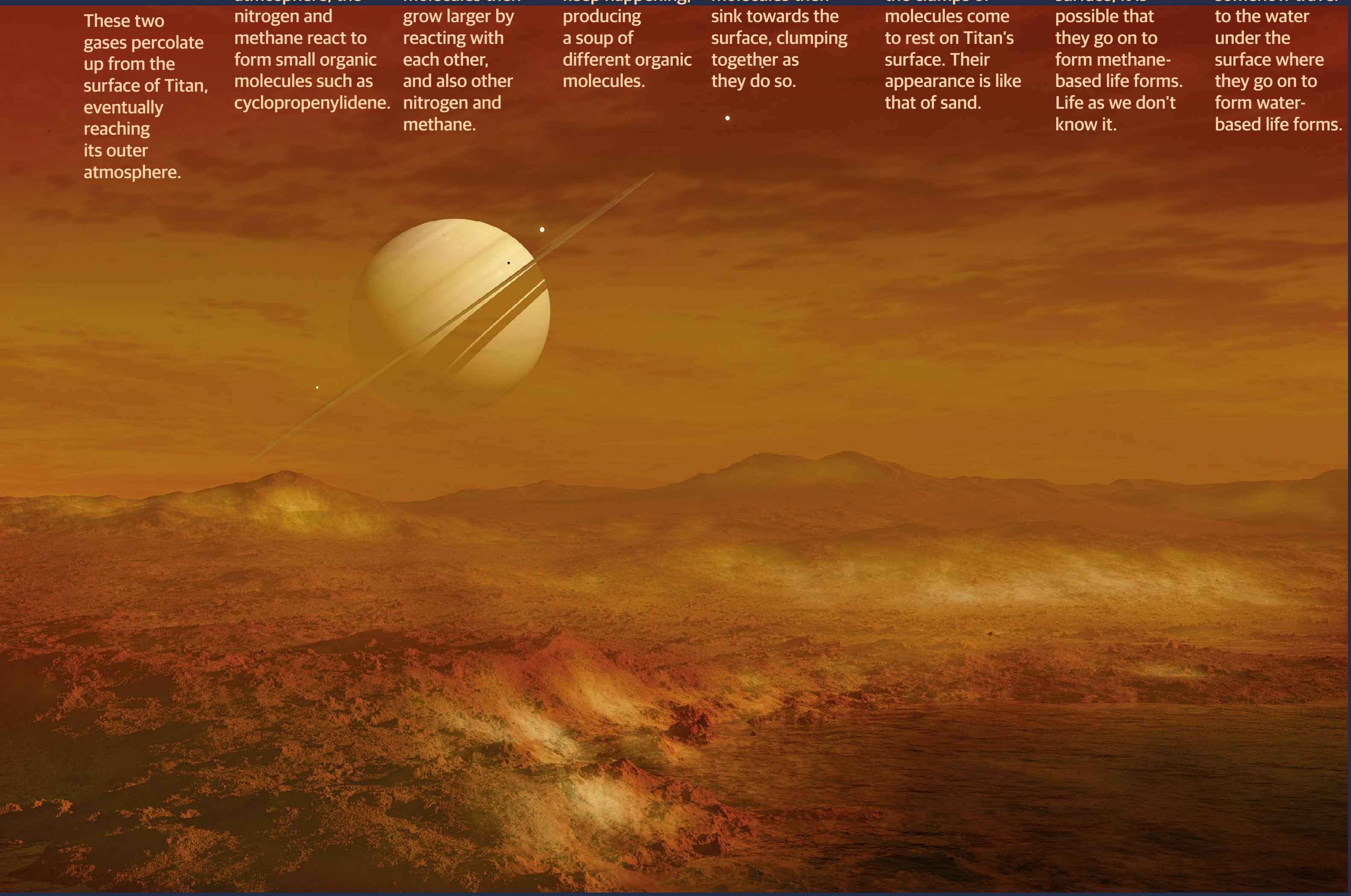
Eventually the clumps of molecules come to rest on Titan's surface. Their appearance is like that of sand.

7. Forming new life?

Once on the surface, it is possible that they go on to form methane-based life forms. Life as we don't know it.

8. Or life as we know it...

They may also somehow travel to the water under the surface where they go on to form water-based life forms.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molecular fingerprints are analogous with our fingerprints. Cyclopropenylidene wasn't actually on the list of molecules Nixon's team had expected to find. They were searching for some larger nitrogen-containing rings instead. "We didn't find those this time around, although I still have hope for the future. But we did find this cool triangular molecule instead, which caught us by surprise," says Nixon.

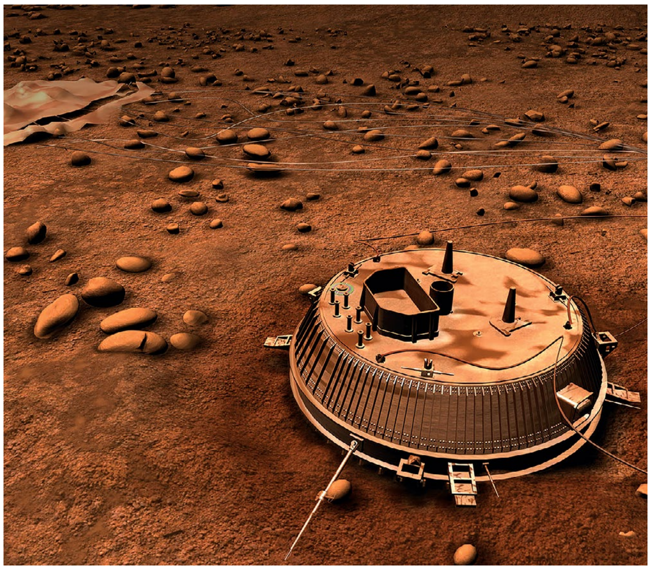
It wasn't only that they weren't looking for cyclopropenylidene at that moment, but astronomers had never planned to search for it in Titan's - or any other body's - atmosphere at all. This is because cyclopropenylidene isn't very stable. It loves to react with other molecules nearby to form more stable new molecules, so if it did form in an atmosphere, the expectation was that it would react again in the blink of an eye. In other words, it would be here and gone before we could possibly detect it. This little triangle has been found lots of times before in the galaxy, but only in the vast clouds of gas and dust that float between star systems. These regions are very cold and the molecules are large distances apart, hindering any onwards chemical reactions. In a warmer, far more tightly packed atmosphere, its lasting presence had seemed extremely unlikely.

Nixon's group spotted a second, less surprising but previously unseen organic molecule in the same location this year too: cyanopropyne. This finding was reported in *The Astrophysical Journal Letters*. Cyanopropyne contains four carbons, three hydrogens and one nitrogen and is straight rather than a closed loop. "This molecule is another of these larger hydrocarbon components that we've been looking for," explains Alexander Thelen, an astrobiologist colleague of Nixon's who led this study. In other words, another of the blocks that could potentially be used to build up life.

Michael Malaska, a planetary scientist at NASA's Jet Propulsion Laboratory, explains the importance of locating these small organic molecules in Titan's

Left: Infrared image of Titan created using 13 years of Cassini mission data

Below: An artist's impression of the Huygens probe on Titan's surface



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HOW TITAN HAS THE INGREDIENTS FOR LIFE

It's this moon's similarities to Earth that have drawn alien life hunters towards it

1. It has an atmosphere

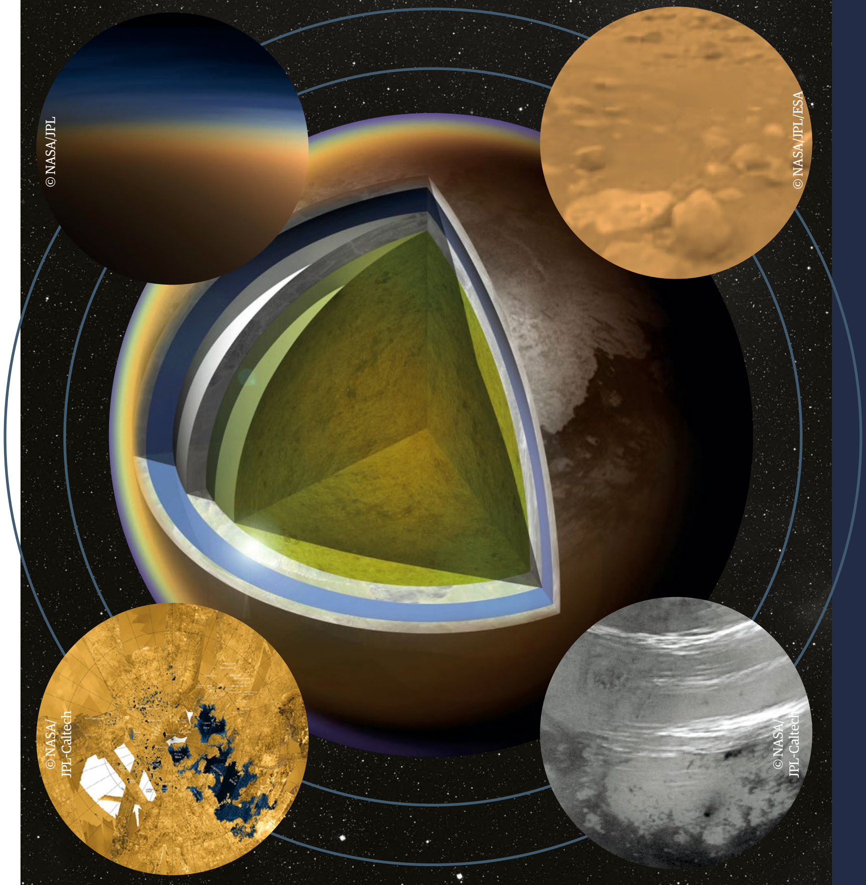
Titan has a thick, dense atmosphere that extends 600 kilometres (373 miles) upwards from the surface. This protects its surface from damaging radiation.

2. Titan has an energy source

Even though Titan is ten-times further from the Sun than Earth, it is believed to receive enough solar energy to sustain life.

3. Organic material exists on its surface

Titan has plains and dunes coated by organic material thought to have dropped down from its atmosphere. It's assumed the sea and lakebeds do too.



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4. Liquid rests on its surface

About 60 per cent of the human body is water. Titan hosts liquid hydrocarbons on its surface that could potentially support an exotic life form.

5. It likely has water under its surface

It is thought that Titan has liquid water oceans deep under its crust. It is possible that these are inhabited by life as we know it.

6. Titan's weather

Titan has wind and rain that is able to transport organic material around its surface. This could potentially bring the ingredients needed to make life together.

Atmospheric pressure

Earth's atmospheric pressure is one bar. Titan's is a pretty comparable 1.5 bar.

© A. D. Fortes/UCL/STFC

Above: Dragonfly will be able to take off and land numerous times on Titan's surface

TITAN BY THE NUMBERS

1
Titan is Saturn's largest moon

50%
wider than Earth's moon

80
How many minutes light from the Sun takes to reach Titan

600
The depth of Titan's atmosphere in kilometres

127
The number of times Cassini flew by Titan

90
Minutes of data sent by Huygens once on Titan's surface

1.5
Titan's atmospheric pressure in bars

2011
The year the ALMA radio telescope started work

atmosphere in a different way: "We are seeing the basic ingredients. It's like going into a kitchen and seeing chocolate chips, flour and walnuts, and knowing that you could potentially make a cookie out of this stuff."

As mentioned, these organic molecules keep reacting onwards, making larger and larger hydrocarbons. These then sink down towards the surface, clumping together as they travel. "They become these sticky, smog particles, similar to what we saw in the old days in the London pea-soup or in the Los Angeles city smog," explains Nixon. They then eventually land on Titan's surface. But Titan's thick, hazy atmosphere hinders observations. Much of the information we have therefore comes from the 127 flybys the Cassini spacecraft did of the moon, as well as the very short-lived Huygens probe that landed on its surface. Data from this mission is still being sieved through and is still throwing up some interesting findings.

A team led by Anezina Solomonidou at the European Space Agency (ESA) recently used this data to look at the material make-up of nine craters on Titan's surface in more detail than ever before. This work was then reported in the journal *Astronomy & Astrophysics*. As well as the composition of the craters, the scientists considered how they are evolving over time. "They found a lot of organic materials that have been deposited over the craters by wind," says Lopes. "From this we can infer that Titan remains a dynamic world today," adds Solomonidou.

NASA's Dragonfly mission will probe more of the surface of Titan in much more detail after its arrival at the moon in the mid-2030s. Dragonfly is a rotorcraft lander mission being developed at Johns Hopkins Applied Physics Laboratory (APL) through the NASA New Frontiers Program. Its main goal is to investigate how far the cascade of organic chemistry reactions seen in the upper atmosphere progress once on the surface, especially when they've come into contact with liquid – either in the form of hydrocarbons or water that may have come up from below. "We want to see how complicated the prebiotic chemistry has got in a setting where liquid may have interacted with the organics that fizzled out from the sky," says APL planetary scientist and Dragonfly architect Ralph Lorenz. "We don't yet know how complicated things get when that soup has a long time to sit and stew."

The ultimate dream is that Dragonfly will spot chemical signatures that indicate that water-based or hydrocarbon-based life is present on Titan. Another hope among Titan experts is that a number of other missions will follow shortly behind Dragonfly, helping to reveal even more of the secrets of this mysterious, Earth-like world.

> "WE CAN INFER THAT TITAN REMAINS A DYNAMIC WORLD TODAY"
> ANEZINA SOLOMONIDOU

Nina Notman
Space science writer
Nina has a PhD in organic chemistry. She trained as a science writer on *Chemistry World* magazine before going freelance in 2012.

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MYSTERIES OF THE UNIVERSE

WHAT'S UP WITH THE MILKY WAY?

A fast radio burst was detected from within our galaxy for the first time. Are we closer to uncovering their origin?

Reported by David Crookes

On 28 April 2020, two ground-based radio telescopes detected an intense pulse of radio waves. It only lasted a mere millisecond but, for astonished astronomers, it was a major discovery, representing the first time a fast radio burst (FRB) had ever been detected so close to Earth.

Located just 30,000 light years from our planet, the event was firmly within the Milky Way, and it was, to all intents and purposes, almost impossible to miss. The Canadian Hydrogen Intensity Mapping Experiment (CHIME) and the Survey for Transient Astronomical Radio Emission 2 (STARE2) certainly had no problems picking it up. "CHIME wasn't even looking in the right direction and we still saw it loud and clear in our peripheral vision," says Kiyoshi Masui, assistant professor at the Massachusetts Institute of Technology. "STARE2 also saw it and it's only a set of a few radio antennae literally made out of cake pans."

Until that point, all FRBs had been observed outside of our galaxy. "They've been billions of light years away, making them a lot harder to study," says PhD candidate Pragya Chawla from McGill University in Canada. April's discovery was also notable for being the most energetic radio blast that astronomers have ever recorded in the Milky Way, but what made it most exciting is that scientists are now closer to determining the origin of FRBs than at any point since they were originally discovered.

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FRB 200428 BY NUMBERS

3,000

FRB 200428 was 3,000-times brighter than any other magnetar radio signal observed so far

1

Duration of the FRB in milliseconds

30,000

Number of light years away from Earth

30

Number of seconds it would take the Sun to emit as much energy

1

Number of bursts recorded from FRB 200428

FIRST

FRB detected with emissions other than radio waves

30,000,000

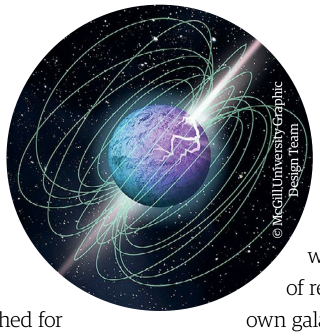
Estimated number of inactive magnetars in our galaxy

30x

less energetic than the weakest extragalactic FRB observed so far

FIRST

FRB firmly linked to a magnetar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Right: An artist's impression of the SGR 1935+2154 magnetar during an outburst, highlighting its complex magnetic field structure and beamed emissions

Below: An artist's impression of a fast radio burst with its different radio wavelengths - red being long and blue short - as they reach Earth

That happened in 2007, when Duncan Lorimer and David Narkevic were studying data taken by the Parkes radio dish in Australia. Discovering an FRB so close to home has been the breakthrough astronomers have wished for ever since. "We can learn more from a source that's 30,000 light years away than one that's a billion or more light years distance," Masui affirms. "We finally have a nearby source to study."

One of the major problems with detecting FRBs - aside from most of them having been so far away - is that they are so fleeting. They've been and gone in the blink of an eye despite being 100 million times more powerful than the Sun - they can release as much energy in a few thousandths of a second as the Sun in 100 years. Ideally, astronomers would discover an object and focus one or more different telescopes at it, but the ephemeral nature of these bursts removes any such opportunity.

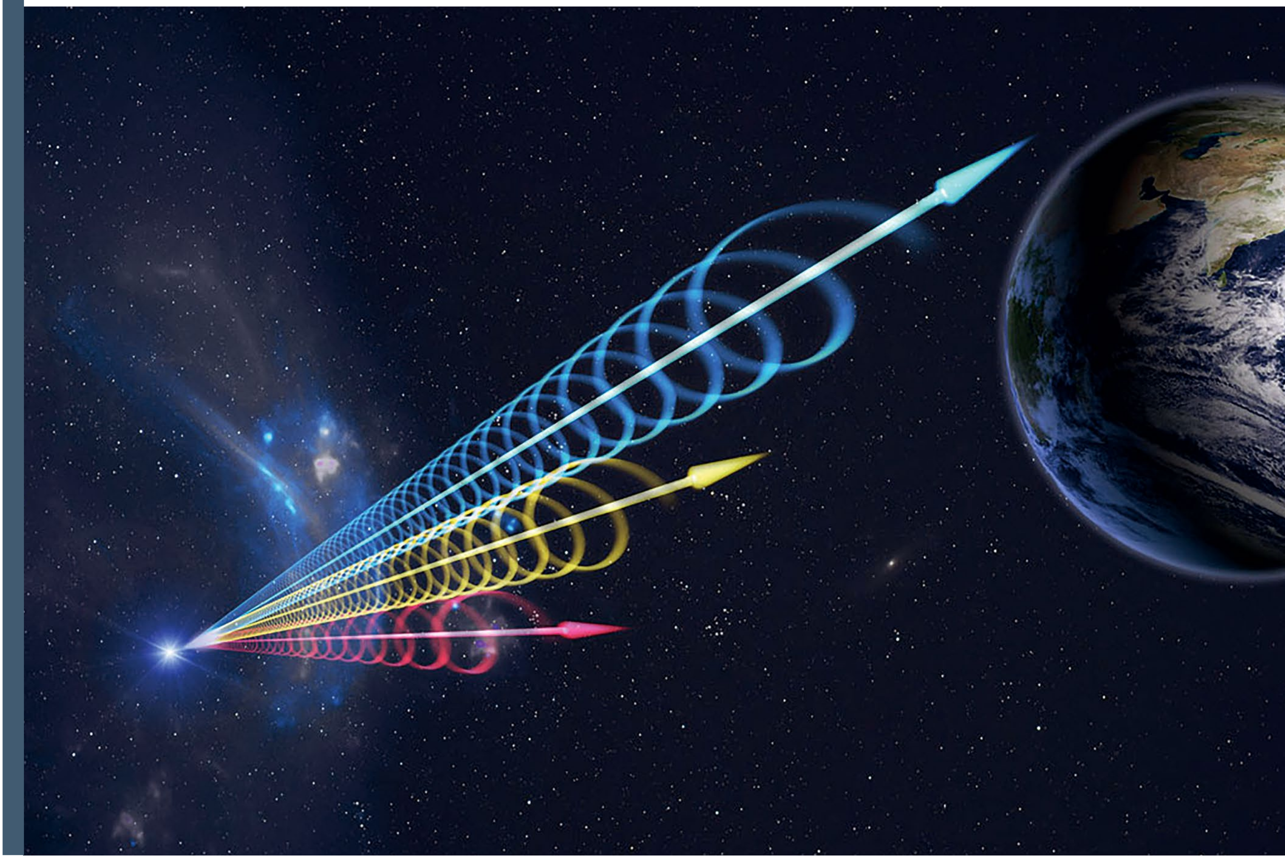
Even so, despite these challenges, astronomers have succeeded in building up a bank of knowledge about FRBs, most of which has been based on the dozens of recorded events from beyond our own galaxy. For starters, we know they are bright flashes of radio light lasting for microseconds to milliseconds. "All-sky searches for them also suggest that thousands of these bursts occur in the sky every day," Chawla adds.

We also know that most of them come from billions of light years away. But while dozens of models have been proposed to explain the origins of FRBs, with progenitors ranging from neutron stars to white dwarfs to cosmic strings, have any theories really prevailed? "Well, we know that they come from very small sources - no more than a few hundred kilometres in size," says Masui. "And the most likely sources are neutron stars since they are both very small and very energetic."

Certainly, the FRB discovered in the Milky Way is allowing astronomers to firm up such theories, and it's become something of a breakthrough for scientists trying to get to the bottom of what is causing them.

Thanks to some nifty cosmic detective work involving the data of other telescopes monitoring the same patch of sky, observational evidence is now suggesting that the origin of FRBs is very

> "WE KNOW THEY COME FROM VERY SMALL SOURCES – NO MORE THAN A FEW HUNDRED KILOMETRES IN SIZE"
>
> KIYOSHI MASUI



likely a magnetar - a type of young neutron star born from the embers of supernovae with a magnetic field 5,000 trillion times more powerful than Earth's, thereby making them the universe's most powerful magnets.

But how has this conclusion been drawn? To explain, we must consider the work that has gone into studying FRBs in relation to magnetars, which are known to emit high-energy electromagnetic radiation, notably gamma rays and X-rays. Both of these erupt in short-lived flares, and there has been speculation that radio waves could be emitted in such a process that would pinpoint magnetars as the source for FRBs.

When this latest FRB was discovered in our galaxy - known by astronomers as FRB 200428 - it was found to have originated in the constellation of Vulpecula, which just so happens to be where the galactic magnetar SGR 1935+2154 is located. It was also accompanied by a burst of X-rays that further excited astronomers.

The first detection of X-rays from that sky region came the day before CHIME and STARE2 discovered FRB 200428. The Neil Gehrels Swift Observatory and the Fermi Gamma-ray Space Telescope detected multiple X-ray and gamma-ray bursts coming from SGR 1935+2154 which was known to exhibit transient radio pulsations.

Other telescopes were also found to have observed an X-ray burst from SGR 1935+2154 - crucially, at the same time of the fast radio burst. These included the Konus-Wind detector on board NASA's GGS-Wind spacecraft and the European Space Agency's INTEGRAL space telescope, both picking up an X-ray burst at the moment CHIME and STARE2 recorded the FRB.

For another check, attention turned to the Five-hundred-meter Aperture Spherical Radio Telescope (FAST) located in southwest China. This fixed-diameter dish telescope was found to have detected a fast radio burst in the direction of FRB 200428 and it put its location somewhere around SGR 1935+2154, which further cemented the association between the X-ray source and fast radio bursts. The latter was comparable to other FRBs found outside the Milky Way, adding to the body of evidence.

"What this means is that the FRB came from the direction of a known magnetar within our galaxy and the radio burst happened at exactly the same time as an X-ray burst coming from the same magnetar," says Masui. "It's a clue as to how magnetars produce FRBs, but the community is still trying to work out what it all means."

What has become clear is that FRB 200428 is the first observed fast radio burst to send out emissions other than radio waves, and scientists have benefitted hugely from having discovered an FRB so close to home. The detection of the X-ray

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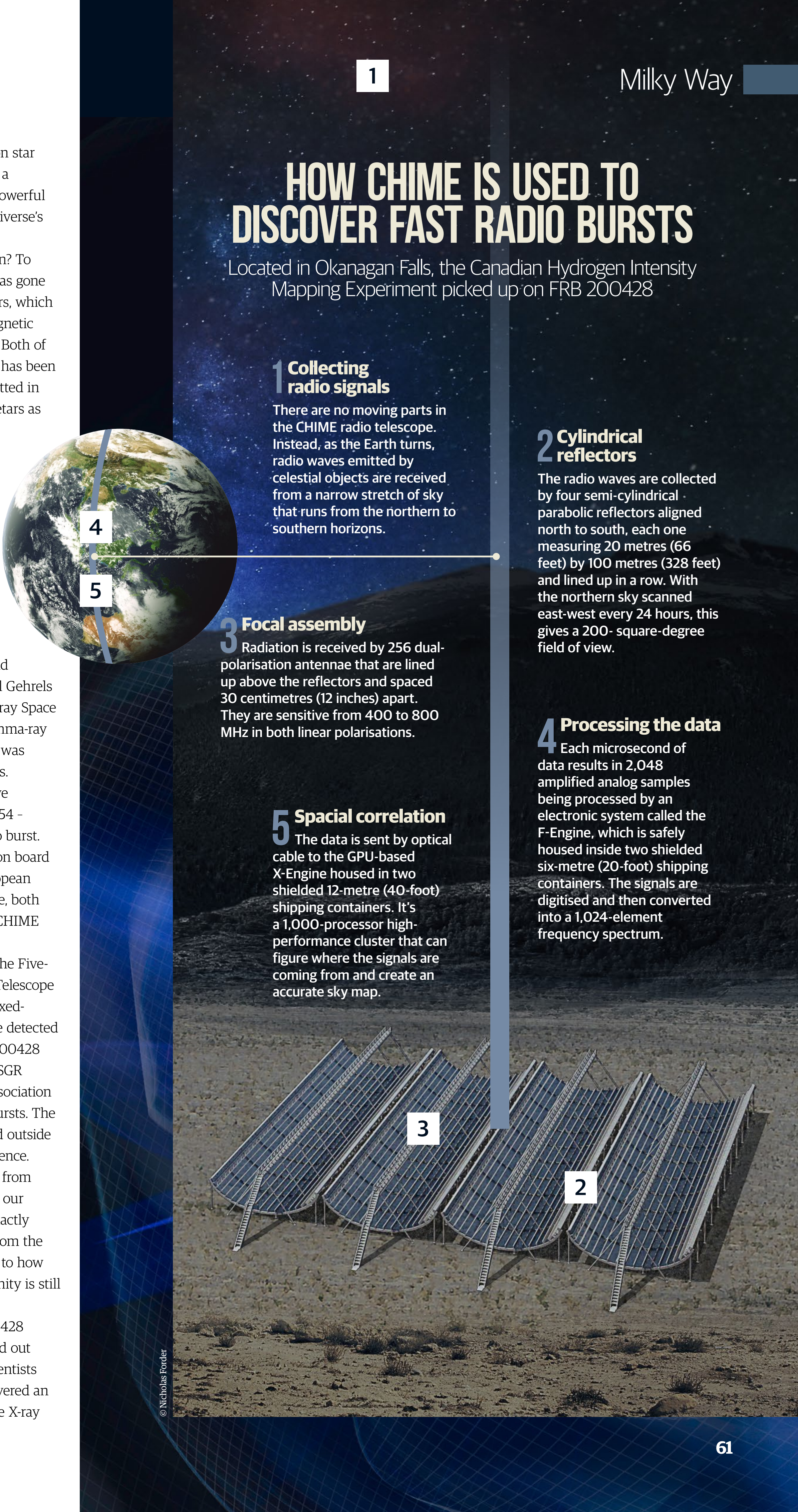


HOW CHIME IS USED TO DISCOVER FAST RADIO BURSTS

Located in Okanagan Falls, the Canadian Hydrogen Intensity Mapping Experiment picked up on FRB 200428

1 Collecting radio signals

There are no moving parts in the CHIME radio telescope. Instead, as the Earth turns, radio waves emitted by celestial objects are received from a narrow stretch of sky that runs from the northern to southern horizons.

2 Cylindrical reflectors

The radio waves are collected by four semi-cylindrical parabolic reflectors aligned north to south, each one measuring 20 metres (66 feet) by 100 metres (328 feet) and lined up in a row. With the northern sky scanned east-west every 24 hours, this gives a 200- square-degree field of view.

3 Focal assembly

Radiation is received by 256 dual-polarisation antennae that are lined up above the reflectors and spaced 30 centimetres (12 inches) apart. They are sensitive from 400 to 800 MHz in both linear polarisations.

4 Processing the data

Each microsecond of data results in 2,048 amplified analog samples being processed by an electronic system called the F-Engine, which is safely housed inside two shielded six-metre (20-foot) shipping containers. The signals are digitised and then converted into a 1,024-element frequency spectrum.

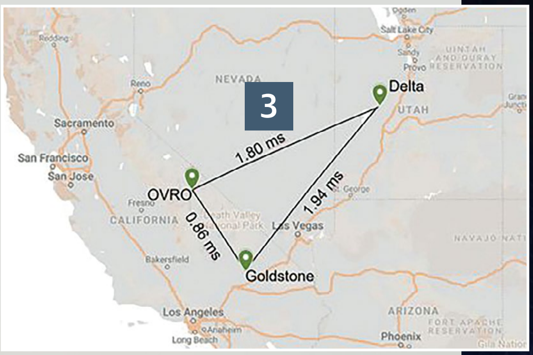
5 Spacial correlation

The data is sent by optical cable to the GPU-based X-Engine housed in two shielded 12-metre (40-foot) shipping containers. It's a 1,000-processor high-performance cluster that can figure where the signals are coming from and create an accurate sky map.

© Nicholas Forder

THE DIY APPROACH TO SPACE DISCOVERY

STARE2's trio of radio detectors were cobbled together by a student using household items



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1 A DIY approach

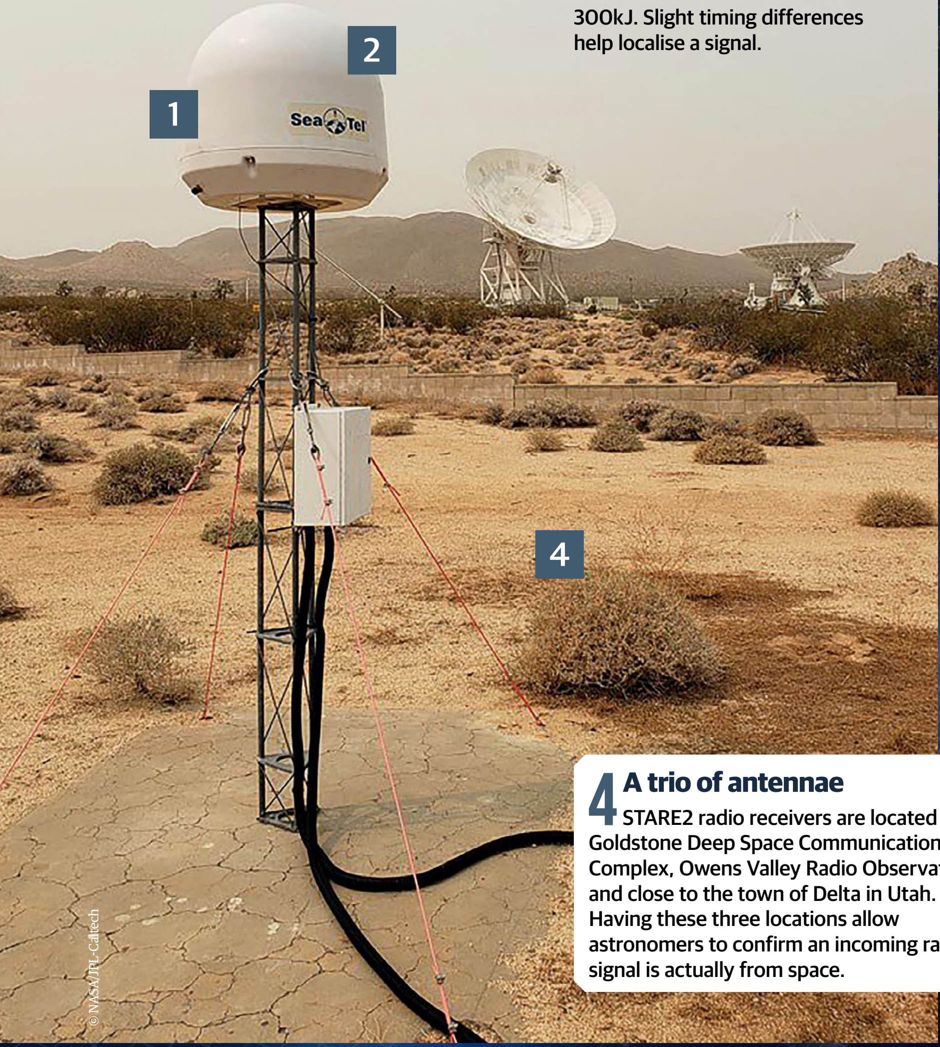
Each antenna is bucket-sized and made from a 15-centimetre (six-inch) piece of metal pipe. This is surrounded by a couple of cake tins that help adjust the instrument's sensitivity. It works like a car antenna.

2 Shielding from interference

The system was built for $15,000 (£11,000) by CalTech student Christopher Bochenek. He even used his Toyota Prius car – which emits radio waves – to test an instrument designed to block unwanted interference.

3 Coverage of the sky

The antennae form a triangle that also enables them to cover the whole visible sky. Combined, STARE2 has a field of view of 3.6 steradians and it's sensitive to one millisecond transients above 300kJ. Slight timing differences help localise a signal.



4 A trio of antennae

STARE2 radio receivers are located at Goldstone Deep Space Communications Complex, Owens Valley Radio Observatory, and close to the town of Delta in Utah. Having these three locations allow astronomers to confirm an incoming radio signal is actually from space.

© NASA/JPL-Caltech

burst at the same time as the radio burst confirmed a magnetar as the origin, and it's the evidence astronomers have been looking for.

"The discovery of an FRB in our galactic neighbourhood is significant because the proximity makes it a lot easier to follow up the source with telescopes observing at other wavelengths," says Chawla. "None of the FRBs ever discovered have been known to emit at any other wavelengths, and this is the first detection of an FRB at a different wavelength. These observations can probe the source environment in greater detail, providing clues about the origin of FRBs."

CHIME in particular has proven to be an essential tool. Based at the Dominion Radio Astrophysical Observatory in Canada, it's a novel radio telescope with no moving parts and it has a high mapping speed thanks to its 200-square-degree field of view and broad frequency range of between 400MHz and 800MHz.

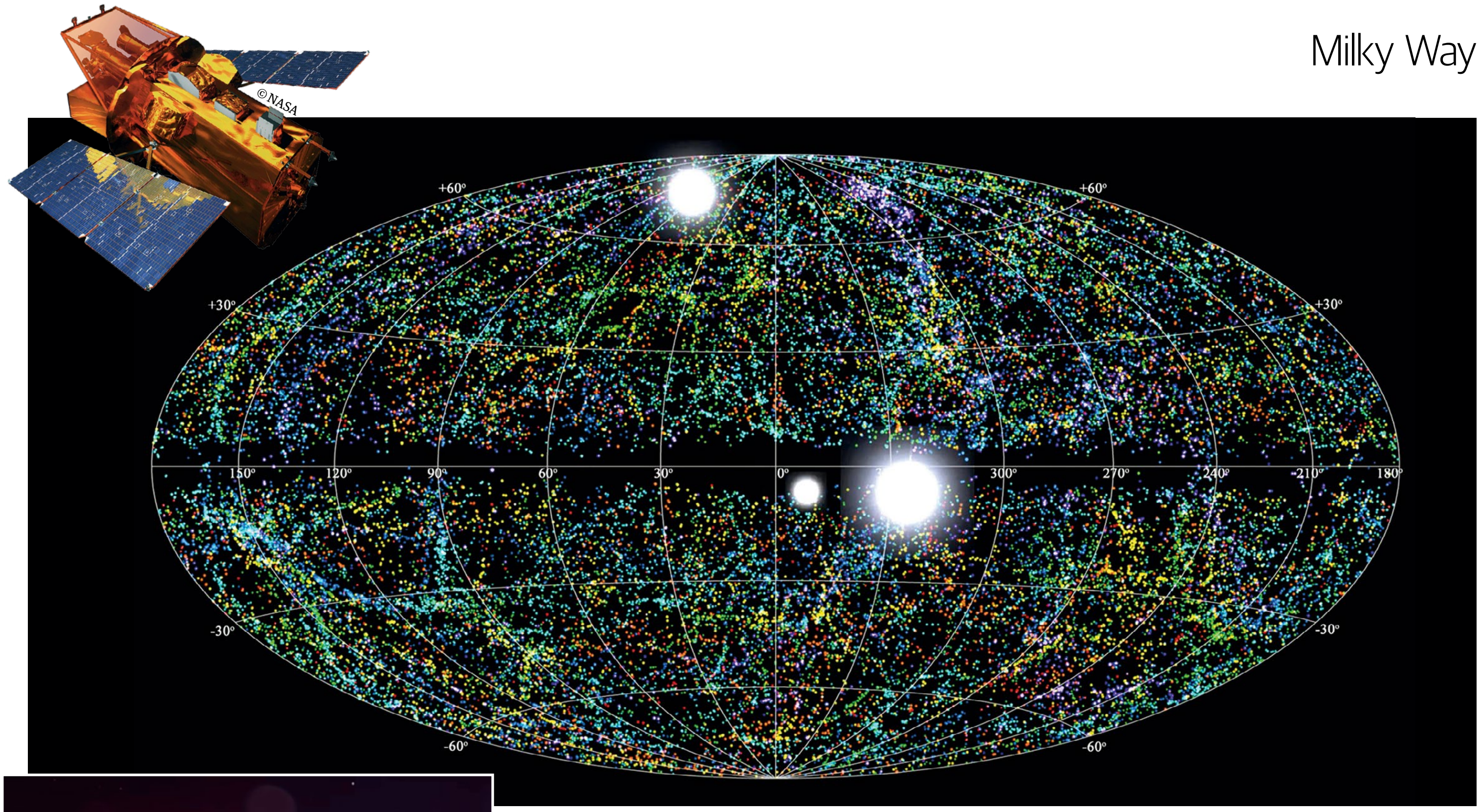
"Most radio telescopes aren't able to pinpoint the location of an FRB well enough to associate it with a known object. Those that are able to localise FRBs with great precision usually look at small patches of sky and can only observe a patch of sky about the size of the full Moon. They are not able to monitor several known magnetars at once," says Chawla.

"CHIME, however, observes an area about 500-times larger and it can therefore monitor all magnetars located in the northern sky every day, allowing us to detect a burst as rare as this one. It combines its localisation capabilities with the large sky area, and that has allowed us to both detect this burst and associate it with a known object."

It's certainly been revolutionary, and it's fast become the main observer of FRBs, with a correlator supercomputer processing 13 terabits of raw data per second to produce a radio map of the sky. "Our ability to detect far-off FRBs has improved dramatically over the past few years," says Masui. "Between 2007 and 2017 roughly 50 FRBs were detected. In the last two years, CHIME has seen several hundred. This is possible because of CHIME's digitally driven design, where the light is focused using digital signal processing, making it able to see large swathes of the sky at once." And yet the case is not entirely closed on this mystery.

As Chawla tells us, young, extragalactic magnetars form only one of the proposed models of FRBs. Bursts from known magnetars in our own galaxy have never been observed to be as powerful as extragalactic ones, and, for the purposes of the study into FRB 200428, astronomers inferred that the burst they detected was 3,000-times brighter than any burst previously observed, thereby making the magnetar model for FRBs more plausible.

"The burst we saw was still less energetic than most extragalactic FRBs, so we cannot say for sure whether magnetars can explain all FRBs," Chawla says of a burst that was a thousandth of the energy of any equivalent found outside the Milky Way.



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> “IT’S BEEN SUSPECTED FOR SOME TIME THAT MAGNETARS MIGHT BE THE SOURCES OF FRBS”
>
> KIYOSHI MASUI

It may well be the case that weaker bursts are more prevalent and it’s simply a matter of this one being close enough to detect. But when it comes to pinning the source of FRBs on magnetars, astronomers need to remember that they come in two guises: those that have repeating signals, which means they frequently generate the outbursts over and over again, and others that, like FRB 200428, generate more infrequently.

It could be the case that infrequent FRBs are caused by magnetars and the frequent ones are caused by a different phenomena. On the flip side, it could also mean that two types of magnetars may exist, causing the two different types of fast radio bursts, or even that the brightest FRBs are caused by objects other than magnetars. Only further research will shed light on the answer, since all we can really say for sure is that we know at least some fraction of FRBs come from magnetars

“It’s been suspected for some time that magnetars might be the sources of FRBs, but this confirms it for at least some fraction of them since we’ve seen it happen once,” Masui says. “But we still don’t know how magnetars create them – we know the ‘what’ and next is the ‘how’: how do magnetars do it?”

As such, it remains important to discover what powers an FRB to emit such energy – perhaps electrons interacting with magnetic fields creating an ‘engine’ of sorts. “We would be interested in determining how extreme the properties of these magnetars need to be to allow a burst from it to be seen across the universe,” says Chawla. “But the most interesting application of FRBs would be to use them as cosmological probes to study the distributions of electrons and magnetic fields in the universe with unprecedented detail.”

Astronomers will also continue to look at how X-ray emissions and these bright bursts of energy are able to occur at the same time. “Whether or not all FRBs are created through the same mechanism is an outstanding question, and it’s subject to much debate among astronomers,” concludes Masui. Given that, it’s clear astronomers will be delving into the ongoing mystery of fast radio bursts for some time.

David Crookes
Science and technology journalist
David has been reporting on space, science and technology for many years, has contributed to many books and is a producer for BBC Radio 5 Live.

Top: The Neil Gehrels Swift Observatory was the first spacecraft to detect activity from the galactic magnetar SGR 1935+2154, on 27 April 2020

Above: An illustration of how fast radio bursts appear randomly across the sky

Right: Astronomers were astonished to discover that, as well as firing off an X-ray burst, SGR 1935+2154 also sent out an extremely brief pulse of radio waves

A MYSTERY SOLVED?

The detection of an FRB in our galaxy has led astronomers to conclude such bursts involve a magnetar

At long last, astronomers can now say with great certainty that fast radio bursts, or FRBs, have a magnetar as their source. It had long been theorised that these dead magnetic stars – spinning remnants resulting from the explosion of a massive star – were a potential source. But only now, with the discovery of FRB 200428, has there been firm evidence for such a theory. Being able to place this FRB in the same area of sky as magnetar SGR 1935+2154 was the breakthrough needed, particularly when an X-ray burst occurred simultaneously. Now astronomers will work to find out if magnetars are behind every FRB.

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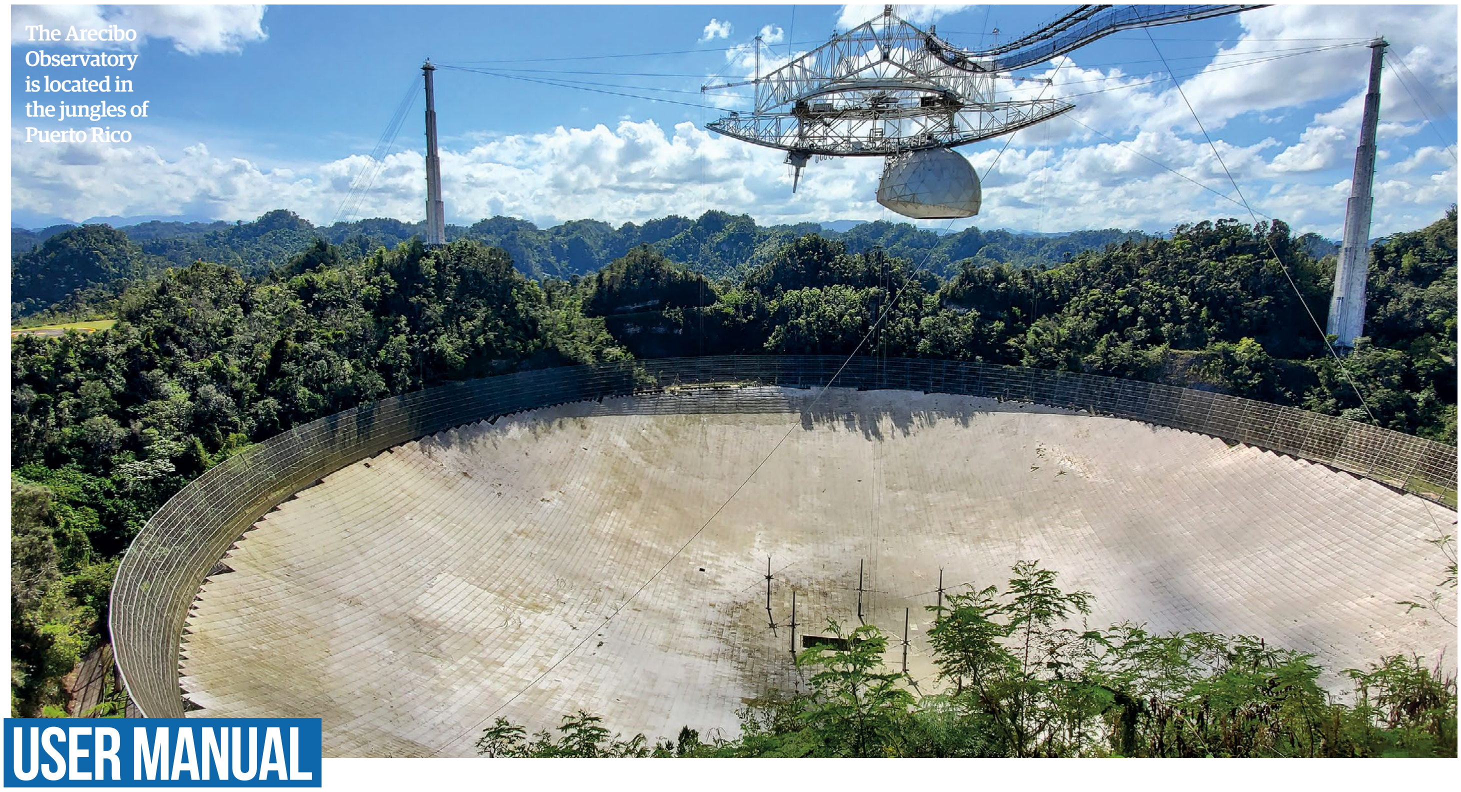


The Arecibo Observatory is located in the jungles of Puerto Rico

Source: Wikipedia Commons © Mariordo (Mario Roberto Durán Ortiz)

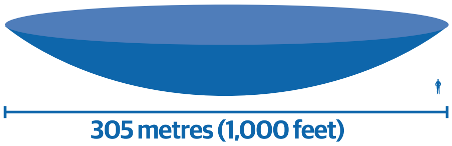
USER MANUAL

Arecibo Observatory

Prior to its decommissioning and sudden collapse, this huge dish made many invaluable contributions to astronomy

THE SPECS

Dish diameter: 305 metres (1,000 feet)
Curvature radius: 265 metres (870 feet)
Number of panels: 38,778
Transmission power: 20TW at 2380MHz
Receiver weight: 900 tonnes
Receiver height: 150 metres (492 feet)
Official opening: 1 November 1963
Decommission order: 19 November 2020



Welcome to the National Astronomy and Ionosphere Center, better known as the Arecibo Observatory. The observatory's 305-metre (1,000-foot) radio telescope dish was completed in 1963, but in November 2020 it was flagged for decommissioning and eventual demolition.

Until 2016 it was the world's largest single-aperture telescope, and it was involved in many exciting radio astronomy discoveries, as well as collecting data in an attempt to detect alien life. It appeared in many films, video games and TV shows and once boasted a visitor centre that welcomed nearly 100,000 visitors a year.

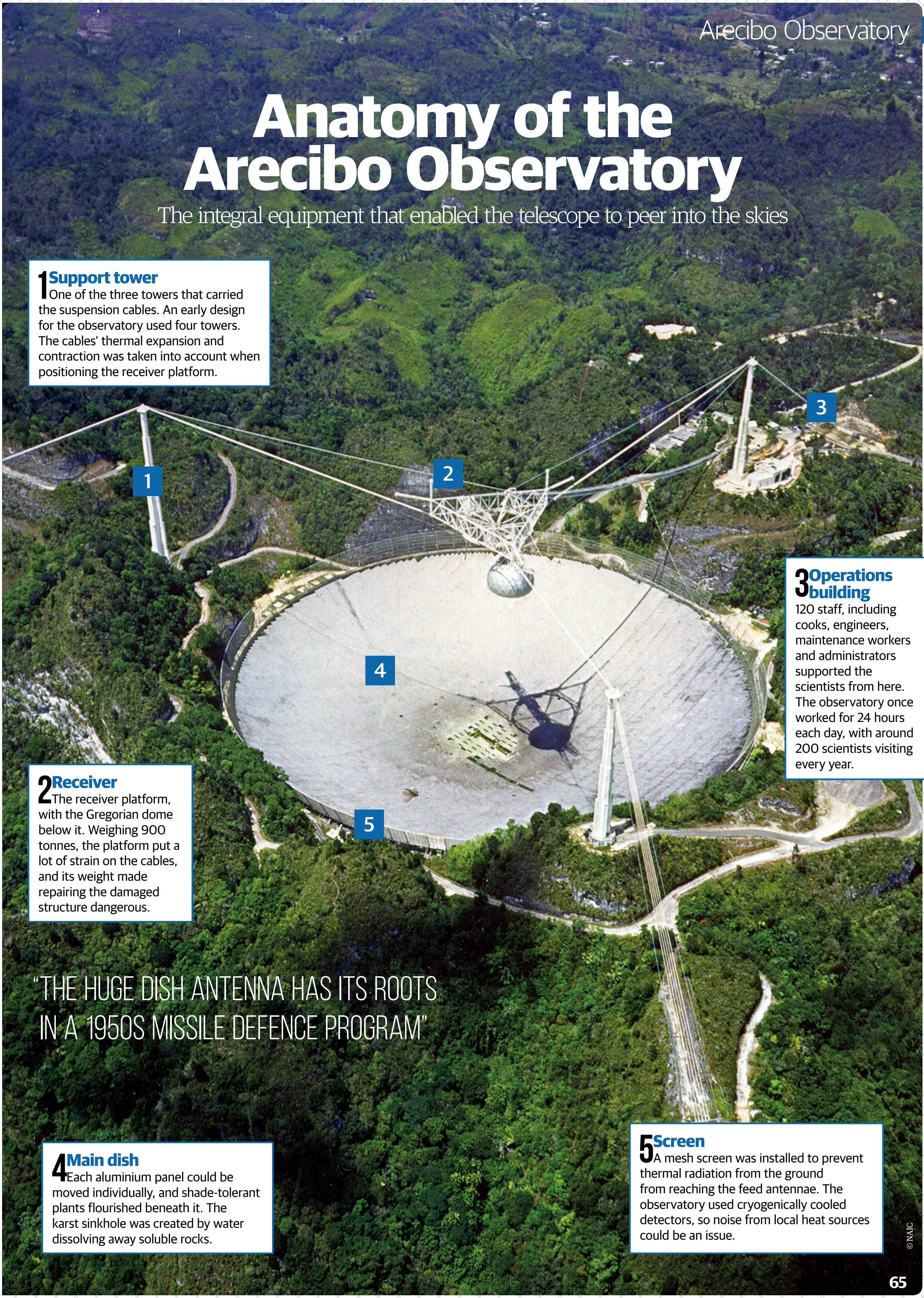
Nestled in the rainforest of Puerto Rico inside a depression left by a sinkhole, the huge dish antenna has its roots in a 1950s missile defence program. The problem was that incoming nuclear weapons could drop radar decoys as they reentered the atmosphere, making it impossible to tell which were real and which were decoys. By studying the upper levels of the atmosphere it was hoped enough knowledge could be gleaned to tell the bombs from the duds. Early in its life, the telescope also helped locate Soviet radar installations by detecting their signals bouncing off the Moon.

William E. Gordon of Cornell University (located in Ithaca, New York) oversaw its design, originally of wire mesh but later comprising thousands of perforated aluminium panels together to create a spherical reflector. This meant that, although the dish itself could not move, it could be 'pointed' by moving the receiver suspended 150 metres (492 feet) above the dish. 18 steel cables ran from three towers around the dish's rim to support the receiver platform, which allowed the telescope to look anywhere in a 40-degree cone of visibility. This, coupled with its location close to the Tropic of Cancer, allowed it to observe Solar System objects closer than Saturn directly with its radar - in 1994 it was used to map ice in the polar regions of Mercury - as well as receive radio waves from anything that crosses its field of view.

Examples of this include 1968 studies of the Crab Pulsar, the neutron star at the heart of the Crab Nebula in Taurus. Arecibo was able to gather early evidence that neutron stars even exist and measured the pulsar as pulsing once every 33 milliseconds. In 1974 it was involved in a Nobel Prize-winning discovery, that of the first binary pulsar - two neutron stars in orbit around a shared centre of mass. In 1989, the observatory became the first to directly image an asteroid, and in 1990 it helped discover the first extrasolar planets, three worlds in orbit around a pulsar in Virgo.

Anatomy of the Arecibo Observatory

The integral equipment that enabled the telescope to peer into the skies



1 Support tower
One of the three towers that carried the suspension cables. An early design for the observatory used four towers. The cables' thermal expansion and contraction was taken into account when positioning the receiver platform.

2 Receiver
The receiver platform, with the Gregorian dome below it. Weighing 900 tonnes, the platform put a lot of strain on the cables, and its weight made repairing the damaged structure dangerous.

3 Operations building
120 staff, including cooks, engineers, maintenance workers and administrators supported the scientists from here. The observatory once worked for 24 hours each day, with around 200 scientists visiting every year.

4 Main dish
Each aluminium panel could be moved individually, and shade-tolerant plants flourished beneath it. The karst sinkhole was created by water dissolving away soluble rocks.

5 Screen
A mesh screen was installed to prevent thermal radiation from the ground from reaching the feed antennae. The observatory used cryogenically cooled detectors, so noise from local heat sources could be an issue.

> "THE HUGE DISH ANTENNA HAS ITS ROOTS IN A 1950S MISSILE DEFENCE PROGRAM"

© NAIC

Source: Wikipedia Commons © Mutante

Inside the Arecibo Message

A letter to the cosmos, beamed from the huge dish towards globular star cluster M13 in Hercules

1 Numbers

These are the numbers one to ten binary format. An alien civilisation was thought more likely to recognise the binary notation than any other method of representing numbers.

2 DNA elements

The numbers 1, 6, 7, 8 and 15, again in binary. These are the atomic numbers of hydrogen, carbon, nitrogen, oxygen and phosphorus, the elements from which DNA is built.

3 Nucleotides

More DNA building blocks, this time the chemical groups from which the nucleotides of polymeric DNA sequences are built, expressed as sequences of five elements.

4 The double helix

There was no colour information in the original message the colours here have been added to make it easier for Earthlings to read. This is the shape of DNA, with a central bar representing the number of nucleotides in humans.

5 Human figure

There are two binary numbers here. On the left of the figure is the average US male's height in 1974, while on the right is the population of Earth in the same year, 4.3 billion people.

6 Solar System

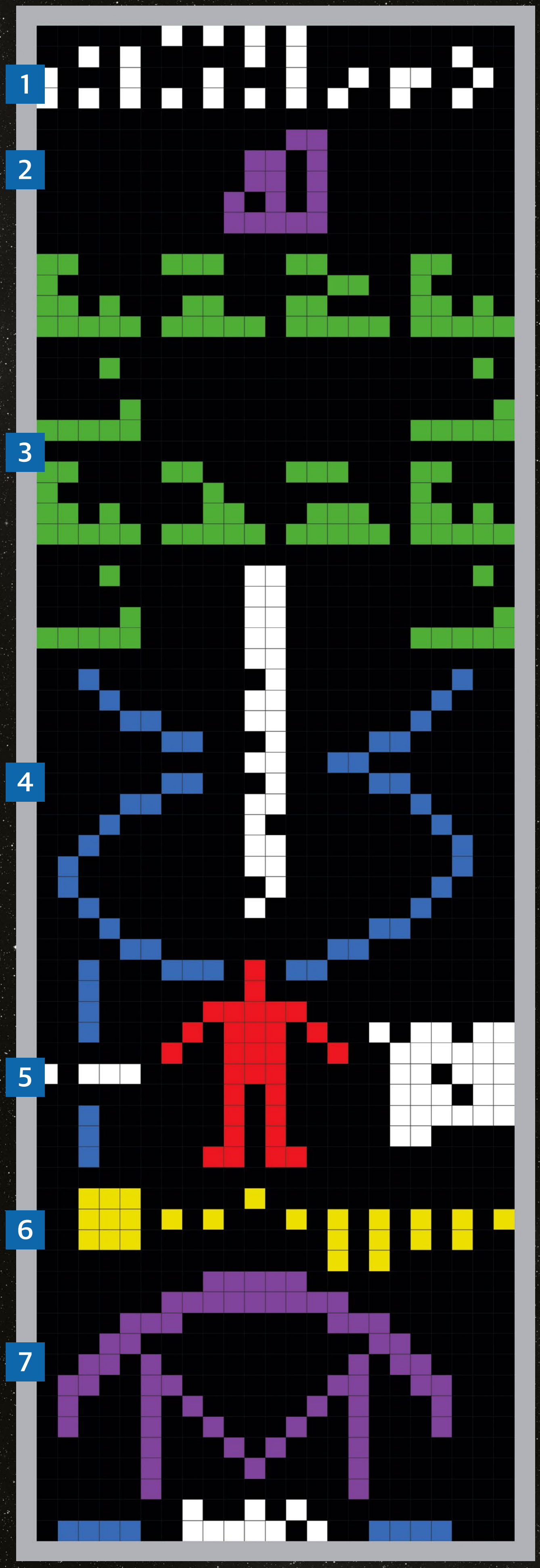
The Sun, eight planets and Pluto – still considered the ninth planet at the time of the message – spaced according to their distance from one another. Earth is shifted upwards to identify it as the source of the message and falls under the human figure.

7 The dish

Arecibo's massive dish, with a binary representation of its diameter. The 'M' demonstrates it is a concave curved mirror.

8 The 'reply'

A crop circle that appeared in a field in Hampshire in 2001 was formatted like the Arecibo Message but included alien data, such as swapping silicon for carbon. It was 23 metres (75 feet) wide and 36.5 metres (120 feet) long.



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Sadly, modern times have not been as kind to the telescope. Hurricane Maria, in September 2017, caused one of the line feeds to the receiver platform to break and fall on the dish, damaging around 30 of the panels. There was damage from earthquakes in 2019 and 2020, then an auxiliary cable broke in August 2020, leaving a 30-metre (98-foot) gash in the dish, followed by another in November 2020. This latter break was one of the main support cables for the platform, which has been left in danger of collapsing. Repairing the cables has been classified as too dangerous, and it was announced on 19 November that the telescope would be decommissioned and dismantled. As if aware of its fate, the telescope's instrument platform collapsed onto a reflector disc below it on 1 December.

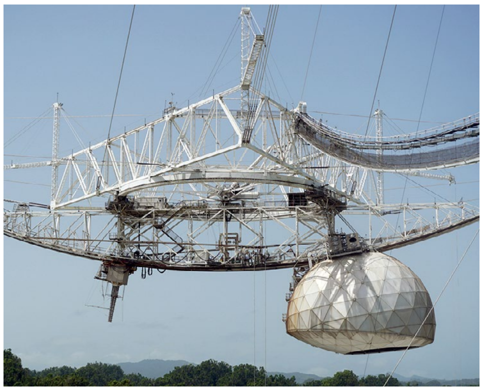
This isn't necessarily the end for the observatory, however, as there are other facilities at the site beyond the main dish, including the use of LIDAR to study the atmosphere, and a second telescope used for very-long-baseline interferometry. It is, however, quite possibly the final act for its movie career, which has seen the dish appear in films including *GoldenEye* and the sci-fi horror *Species*.

Arecibo's contributions cannot be underplayed, but it is now up to other telescopes to take up the baton. The Five-hundred-meter Aperture Spherical Telescope in China, as well as Australia's Square Kilometre Array and Russia's RATAN-600, will take over the job of listening to faint radio from outer space and searching for those little green men.

TOP TECH

Frequent frequency fiddling

Originally, the maximum frequency used by the telescope was expected to be 500MHz. A surface of wire mesh was considered good enough to support this. When the surface was replaced with adjustable aluminium panels in 1973, the usable frequency rose to 5,000MHz. In 1997, a Gregorian reflector was installed – its dome can be seen hanging from the azimuth arm. This can be positioned up to 20 degrees from vertical and contains two reflectors for focusing radio waves in the 1 to 10GHz range. The same year, a 2,400MHz transmitter was also added.

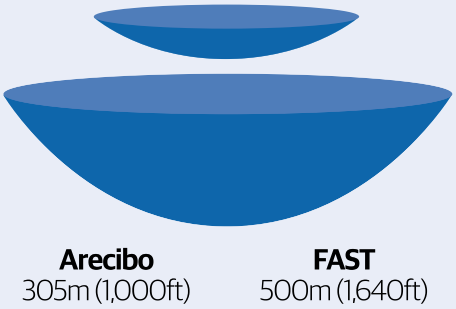


Source: Wikipedia Commons © Mariordo (Mario Roberto Durán Ortiz)

Head-to-head

Arecibo vs FAST

The Five-hundred-meter Aperture Spherical Telescope, located in southwest China (also known as the Eye of Heaven), became the largest filled-aperture radio telescope in the world upon its completion in 2016. Beating Arecibo by 200 metres (656 feet) in diameter, it sits in a natural depression in the landscape and became fully operational in January 2020. Built as a geodesic dome, it is made of 4,450 triangular aluminium panels moved by 2,225 winches to form a 300-metre (984-foot) diameter parabolic antenna facing in the desired direction. Radio waves are focused on a feed cabin suspended 140 metres (459 feet) above the dish by six support towers. It works in the 70MHz-3GHz frequency range.



Vital statistics

2.6 HOURS = The time the telescope took to image a single object

5,000 MHZ = The highest frequency the dish could detect

38,778 = The number of plates that made up the dish

900 TONNES = The weight of the receiver suspended above the dish

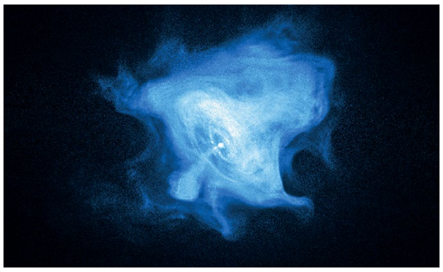
2,400 MHZ = The highest frequency the dish could transmit

HOW TO...

Discover the universe using a radio telescope

1 Crab Pulsar

Both the period and location of the Crab Pulsar, the central star in the Crab Nebula, were discovered from Arecibo. The pulsar is a neutron star, and the nebula is the remnant of a supernova event in the year 1054.



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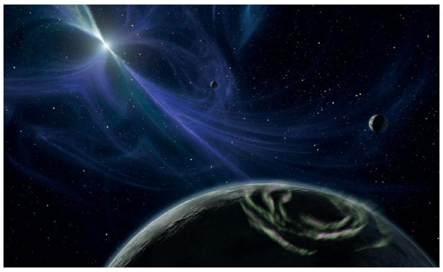
2 First-ever exoplanet

Not just one exoplanet but an entire system, orbiting the pulsar PSR B1257+12. The three worlds are named Draugr, Poltergeist and Phobetor, with the pulsar taking the name Lich.



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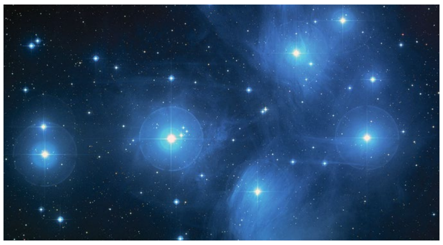
3 Pleiades distance

How far the Pleiades – an open cluster of B-type stars in Taurus – are from Earth has been a source of debate. Arecibo measurements suggested 133 parsecs, while the Hipparcos satellite went for 120. Gaia, Hipparcos' successor, measured the distance as 134 parsecs.



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4 Repeating fast radio burst

Arecibo was able to prove that the mysterious FRBs are extragalactic and discovered the first repeating FRB, showing that the source survived the burst. Current thinking points to magnetars – highly magnetised neutron stars – as their source.

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GREAT SPACE IMAGES OF 202

FROM THE STUNNING WESTERLUND 2 TO THE MIGHTY JUPITER, OUR EYES IN THE SKY HAVE SEEN SOME SPECTACULAR SIGHTS THIS YEAR. HERE ARE JUST A FEW OF THEM

Reported by Baljeet Panesar

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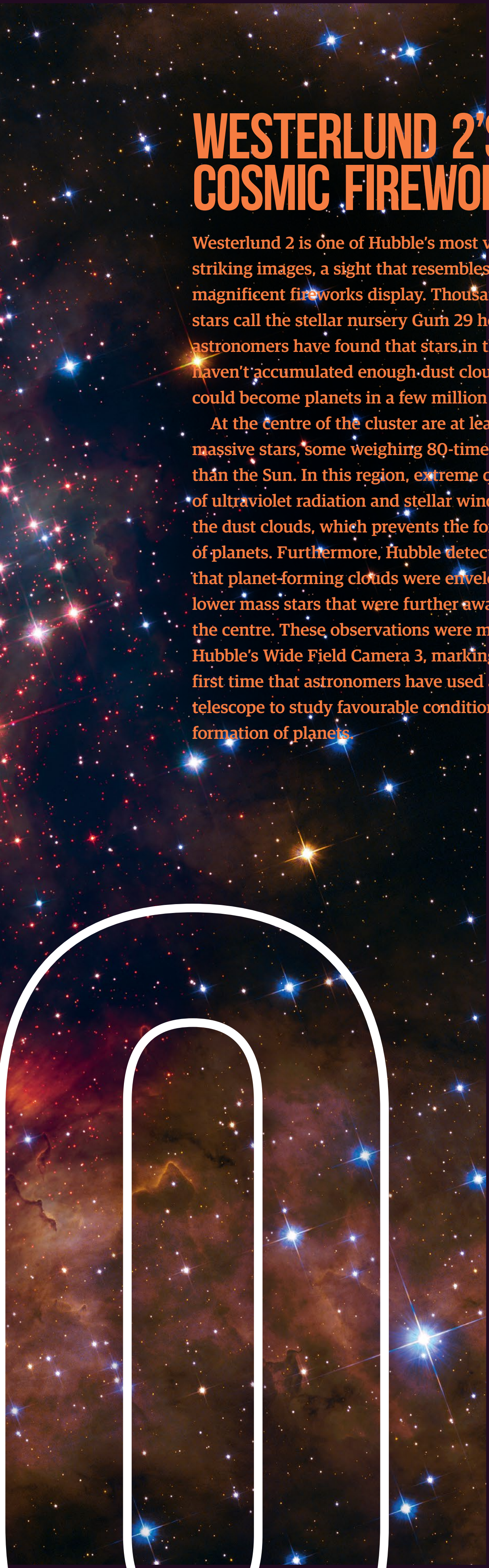
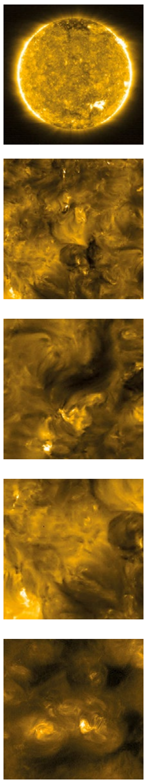


WESTERLUND 2'S COSMIC FIREWORKS

Westerlund 2 is one of Hubble's most visually striking images, a sight that resembles a magnificent fireworks display. Thousands of stars call the stellar nursery Gum 29 home. Yet astronomers have found that stars in the centre haven't accumulated enough dust clouds that could become planets in a few million years.

At the centre of the cluster are at least 30 massive stars, some weighing 80-times more than the Sun. In this region, extreme quantities of ultraviolet radiation and stellar winds disperse the dust clouds, which prevents the formation of planets. Furthermore, Hubble detected that planet-forming clouds were enveloping lower mass stars that were further away from the centre. These observations were made by Hubble's Wide Field Camera 3, marking the first time that astronomers have used a space telescope to study favourable conditions for the formation of planets.



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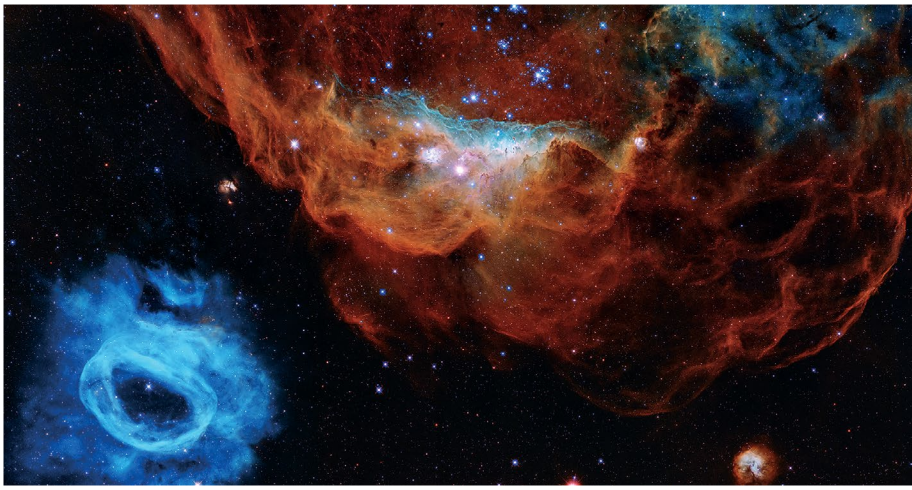
SOLAR ORBITER'S FIRST VIEW OF THE SUN

Solar Orbiter was launched back in February 2020 and carries six telescopes to image the Sun. These first light images, taken in May, show the Sun's surface in exceptional detail, such as has never been seen before. They have revealed 'campfires' – miniature solar flares – captured at a distance of 77 million kilometres (47 million miles) away, roughly half the distance between the Sun and Earth, making them the closest images taken of the Sun at the time. These campfires are just 400 kilometres (250 miles) wide, and they were imaged using the Extreme Ultraviolet Imager (EUI). Despite their small size, these campfires may be contributing to the abnormally high temperature of the corona – something that has long puzzled solar scientists – and they may even be the origin of the solar wind. Eventually the Solar Orbiter will get as close as 42 million kilometres (26 million miles), closer than the planet Mercury, and the mission is expected to last for at least seven years.

HUBBLE'S 30TH ANNIVERSARY IMAGE

Since the Hubble Space Telescope opened its eye to the cosmos 30 years ago, it has taken some of the most magnificent and mesmerising images of the universe. To celebrate the occasion, NASA released this stunning image of a celestial region nicknamed the 'Cosmic Reef'.

The image reveals a large star-forming region in the Large Magellanic Cloud, the largest of the Milky Way's satellite galaxies, located about 163,000 light years away. At the centre of the large red nebula, NGC 2014, is a group of bright stars that are 10 to 20 times more massive than the Sun. These massive stars release powerful winds of charged particles, which sculpt the bubble-like structures. Towards the left of the nebula sits a smaller blue-hued planetary nebula, NGC 2020.



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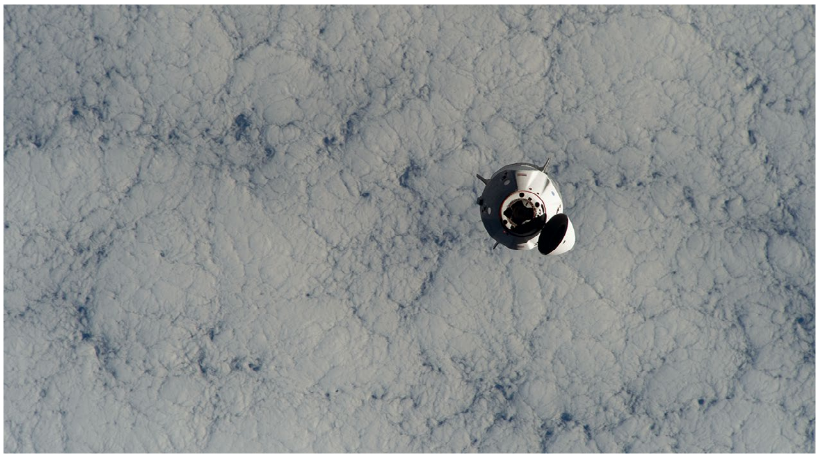
SPACEX CREW-1

2020 has been an exciting year for SpaceX; in May it became the first private spaceflight company to launch a crewed mission to space. In this image the four astronauts – NASA's Mike Hopkins, Victor Glover and Shannon Walker, and JAXA's Soichi Noguchi – are approaching the International Space Station (ISS) after a 27-hour voyage, where they will spend around six months. Behind the Crew Dragon spacecraft, called Resilience, is Earth, enveloped by clouds. This mission has some notable achievements, including the first flight of a NASA certified commercial system for transportation of crew, the first international crew to launch on an US commercial craft and the first time the Earth-orbiting space station will increase crew size to seven to allow more time for research. With the success of the spacecraft docking, NASA has also achieved another of its aims of the Commercial Crew Program, which began in 2011 after the retirement of the Space Shuttles.



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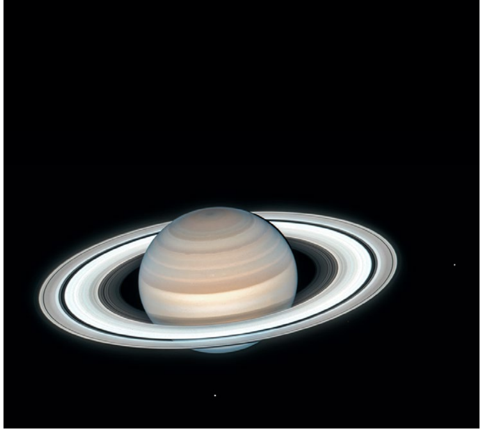

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SATURN 2020

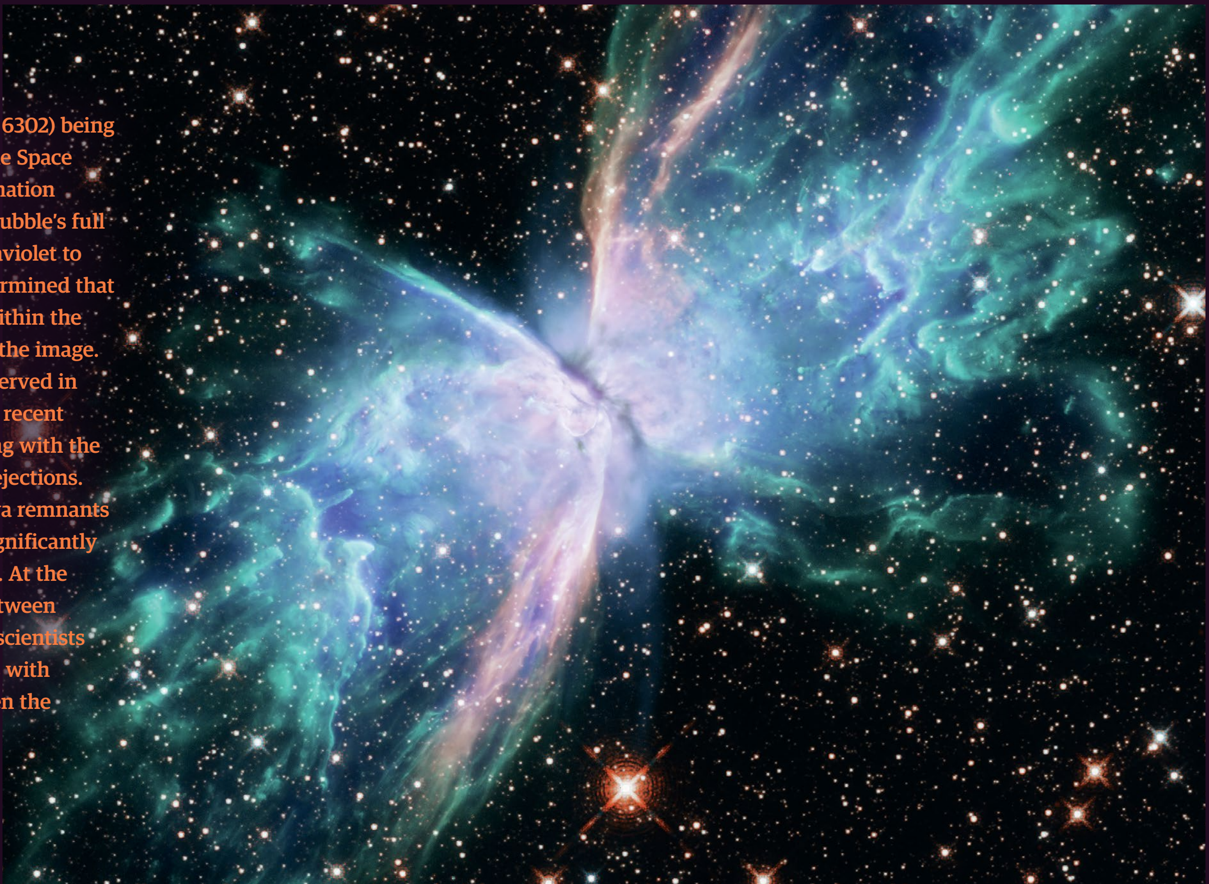
This exquisitely detailed and stunning image of Saturn was taken by the NASA/ESA Hubble Space Telescope when the gas giant was 1.4 billion kilometres (839 million miles) from Earth. The reddish haze in the northern hemisphere shows Saturn in the height of summer. The red colouration is caused by exposure to sunlight. In the south, however, the blue hues of winter are just about visible beneath Saturn's rings.

This image is part of the Outer Planets Atmospheres Legacy (OPAL) project, which started in 2018. The project images each of the outer planets every year to study their weather patterns and evolution, but in previous years Saturn's winter has not been imaged. Future images may tell astronomers more about Saturn's seasonal changes. Two of Saturn's 82 known moons are also visible in this image: the cratered world Mimas on the right and icy Enceladus at the bottom.

BUTTERFLY NEBULA

Despite the Butterfly Nebula (NGC 6302) being one of the most studied, the Hubble Space Telescope has revealed new information about this cosmic wonder. Using Hubble's full wavelength range – from near-ultraviolet to near-infrared – scientists have determined that singly ionised iron can be found within the pink S-shape seen in the centre of the image.

This iron emission was only observed in near-infrared and reveals the most recent violent ejections of hot gas colliding with the slower moving winds of previous ejections. Iron tends to be found in supernova remnants and active galactic nuclei, but is significantly less common in planetary nebulae. At the centre of the nebula, which lies between 2,500 and 3,800 light years away, scientists think that there could be two stars with significantly different masses, given the asymmetrical emission of iron.



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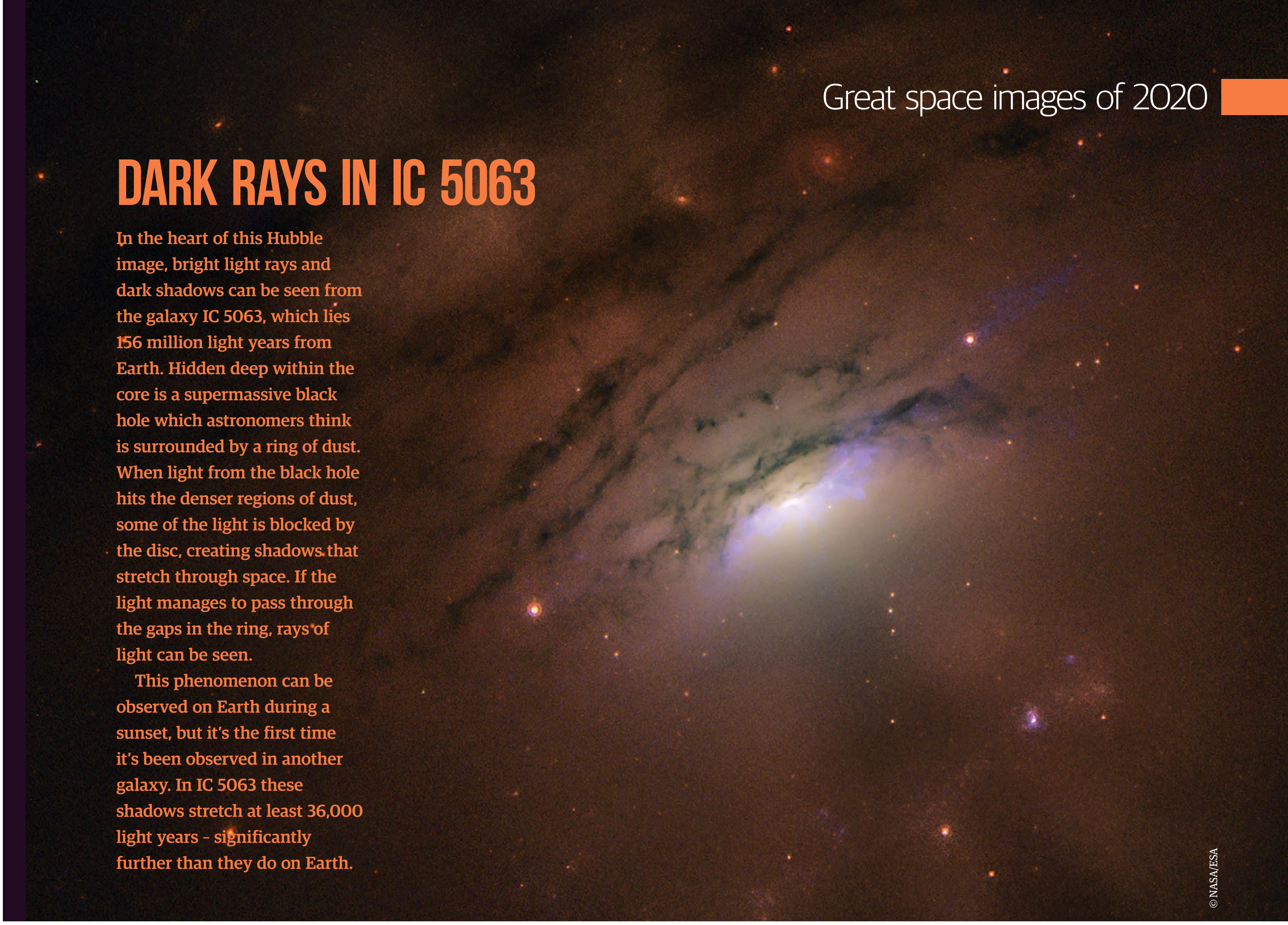

DARK RAYS IN IC 5063

In the heart of this Hubble image, bright light rays and dark shadows can be seen from the galaxy IC 5063, which lies 156 million light years from Earth. Hidden deep within the core is a supermassive black hole which astronomers think is surrounded by a ring of dust. When light from the black hole hits the denser regions of dust, some of the light is blocked by the disc, creating shadows that stretch through space. If the light manages to pass through the gaps in the ring, rays of light can be seen.

This phenomenon can be observed on Earth during a sunset, but it's the first time it's been observed in another galaxy. In IC 5063 these shadows stretch at least 36,000 light years – significantly further than they do on Earth.

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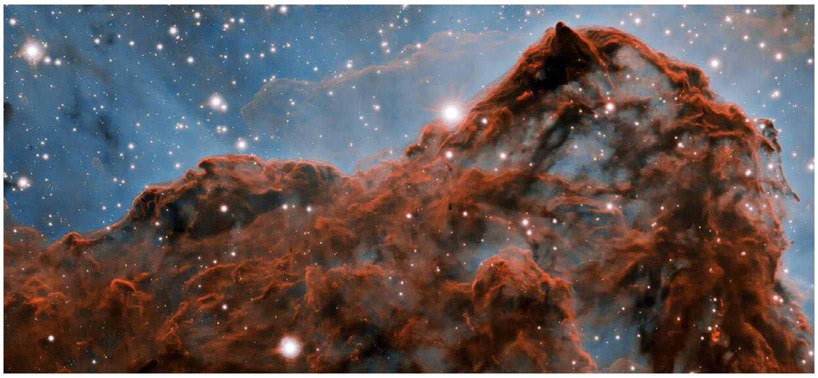

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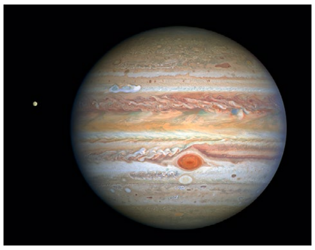
CARINA NEBULA'S WESTERN WALL

Using the 8.1-metre (26-foot) Gemini South telescope at the Gemini Observatory in Chile, the Carina Nebula's western wall – the nebula's edge – can be seen with such great clarity. This detail is visible due to a technology called adaptive optics, which has improved the image resolution tenfold.

This giant section of wall is 50 trillion kilometres (33 trillion miles) long, and it's where the birth of new stars occurs, 7,500 light years from Earth. Observed in infrared, the glowing dust and gas is due to the generation of ultraviolet radiation from star birth. There are also several interesting structures in the mountain-like section: parallel ridges that may be produced by a magnetic field, a near-smooth wave, fragments that are being blown off by the strong stellar wind and a jet from a new star. This technology would allow astronomers to determine how young stars affect their surroundings and how massive stars are born.

JUPITER AND EUROPA 2020

This image of Jupiter and its icy moon Europa was taken by the Hubble Space Telescope when the giant planet was 653 million kilometres (406 million miles) from Earth. In the northern latitudes of the Jovian clouds, a bright-white storm appears to be brewing, moving at around 563 kilometres (350 miles) per hour. Storms appear in this region about every six years. Often several storms appear at once, but this particular storm appears to have more structure.



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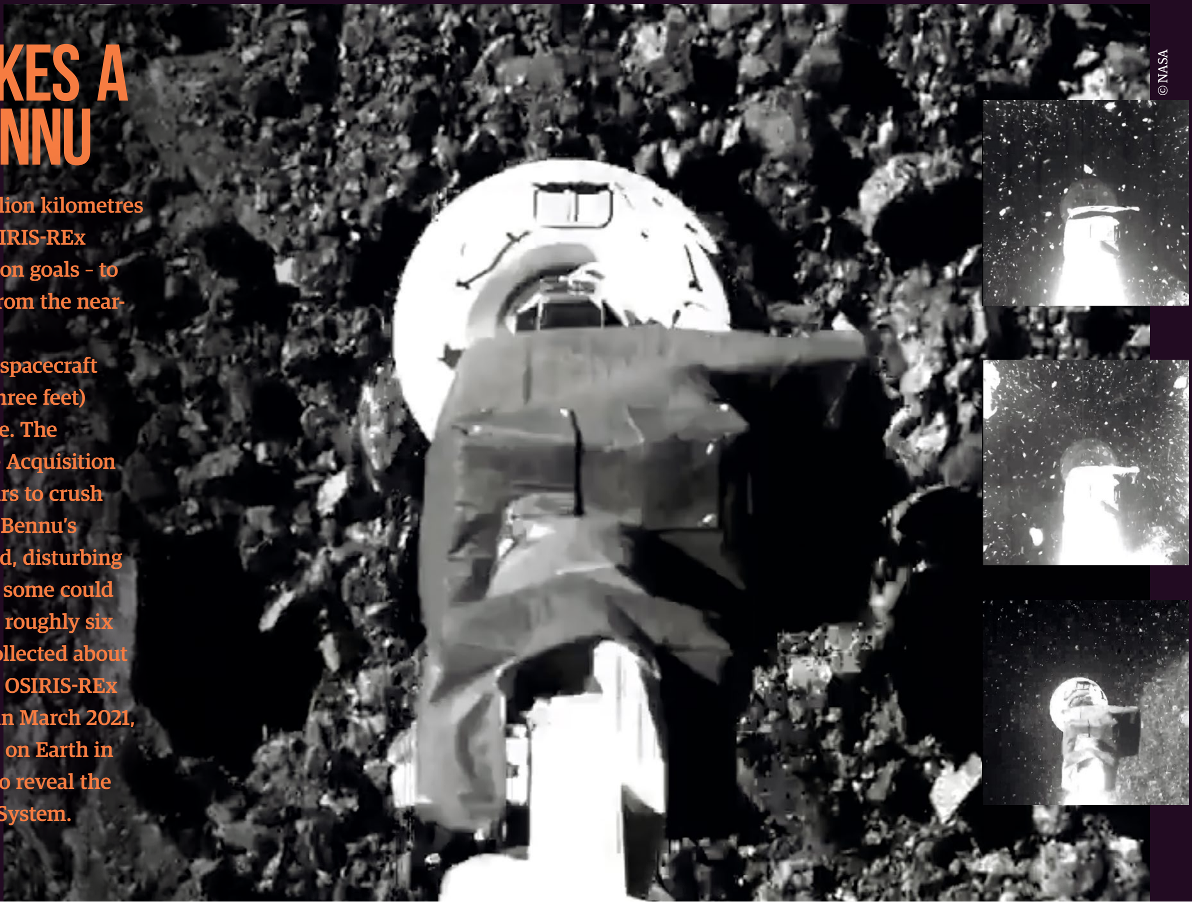
OSIRIS-REX TAKES A SAMPLE OF BENNU

In a NASA first, more than 320 million kilometres (200 million miles) from Earth, OSIRIS-REx has finally realised one of its mission goals – to collect a sample of rock and dust from the near-Earth asteroid Bennu.

This series of images shows the spacecraft descending to within one metre (three feet) of the target site, called Nightingale. The spacecraft's Touch-And-Go Sample Acquisition Mechanism (TAGSAM) head appears to crush the rocks as it makes contact with Bennu's surface. Nitrogen gas was then fired, disturbing the material on the surface so that some could be collected. This manoeuvre took roughly six seconds, and is believed to have collected about 400 grams (14 ounces) of material. OSIRIS-REx will start its voyage back to Earth in March 2021, and once its precious cargo arrives on Earth in September 2023, Bennu will help to reveal the history and evolution of our Solar System.



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COMET NEOWISE

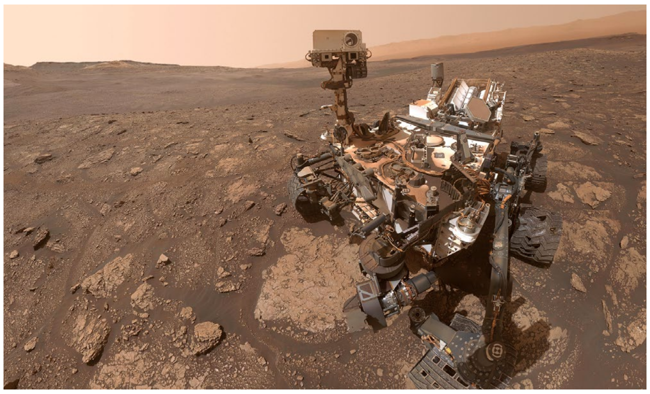
Hubble's spectacular eye was used to image a cosmic visitor, comet C/2020 F3, also known as NEOWISE. Comets can help astronomers learn about the conditions of the early Solar System, but this is the first time that such a bright comet has been imaged after passing the Sun so closely – at just 43 million kilometres (23 million miles). Most attempts at imaging comets are not successful because of the heat and gravitational forces which they are exposed to.

NEOWISE's nucleus seems to have survived, which appears to be less than five kilometres (three miles) across. Hubble captured the comet's coma, the cloud of dust and gas around the nucleus, stretching some 18,000 kilometres (11,000 miles) wide. Two curving jets from the nucleus were released from the comet, caused by the ice turning into a gas. NEOWISE is making its way towards the outer Solar System, eventually returning in about 7,000 years.

CURIOSITY'S MARS SELFIE

Curiosity is well known for taking selfies during its exploration of the Martian surface, and its most recent one was taken at the 'Mary Anning' location. Named after the English palaeontologist and fossil hunter, the area may have had conditions that could have supported life millions of years ago. This image is made from a combination of 59 images and was taken with the Mars Hand Lens Imager (MAHLI) at the end of Curiosity's arm.

Curiosity arrived at the Glen Torridon region in July and has since drilled three samples from the clay-rich area. These drill holes have been named 'Mary Anning', 'Mary Anning 3' and 'Groken' – after cliffs on Scotland's Shetland Islands. This brings the total number of drilled samples collected to nearly 30, and it will take months for scientists to analyse the samples from the Mary Anning site.



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SPACE EXPLORATION

Will the International Space Station ever be replaced?

The short answer? Yes, most definitely. The components for the ISS were designed to last for only 15 years; it is 20 years old now and NASA is talking about keeping it in service until 2024. After that NASA may sell the rest, Russia will most likely disconnect from the ISS and eventually it could be jettisoned back into the atmosphere. This, of course, is hugely wasteful, so it could be recycled in low-Earth orbit. That, I believe, is a better use of a space mass that cost $150 billion (£113 billion) to get there.

Personally, I would break down all the mass into its molecular components then reuse them in space to build something else. Back in 1983 I came up with a construction method for building very large spinning structures in space. I will eventually use lunar materials to build artificial gravity stations or mobile spacecraft with artificial gravity components.

But there most likely will always be a need for orbiting space stations around Earth, the Moon, Mars and eventually all planets - at least one per planet. There will always be a need to have ships for travelling the Solar System and there will always be a need for facilities on the Moon, Mars and other rocky moons and planets.

United Space Structures will build our first lunar facility and then thousands more on the Moon, and help to establish mining operations so that the lunar materials can be constructed into spaceships and space stations. We will then do the same on Mars.

William Kemp is CEO and founder of United Space Structures

Above: The ISS' future will be in the hands of NASA's commercial and international partners after 2024

© Getty

COSMOLOGY

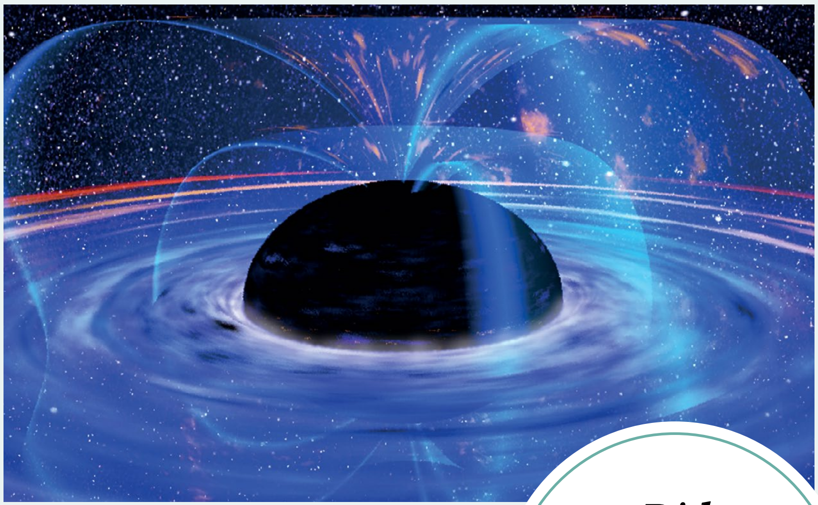
Will the universe end?

There are three widely considered fates for the universe born in a Big Bang. These are the Big Chill, Big Crunch and Big Rip. In the Big Chill scenario, the expansion of the universe continues forever, leaving space-time a cold and lonely place populated by a few island galaxies, like dying embers of the Big Bang.

The expansion halts and reverses in the Big Crunch as the universe collapses under its own weight. The scenario resembles the Big Bang played in reverse, though thermodynamics ensures that entropy is ever increasing. The universe ends… unless the singularity is avoided and the expansion bounces back.

In the Big Rip, the cosmic acceleration is a runaway process that grows in strength. Clusters, galaxies, stars and planets are all torn asunder by the expansion, right down to atoms and finally space itself. Current data suggests the 'end' would not be sooner than about 50 gigayears, or 50 billion years.

Which is our destiny? The fate of the universe is tied up with the nature of dark energy - the mysterious substance that comprises around 75 per cent of the energy of the universe and drives the acceleration of cosmic expansion.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The provisional hypothesis is that dark energy is a rigid stratum of quantum energy, a cosmological constant, which condemns us to an eternity of acceleration and a Big Chill scenario. A leading alternative is that dark energy is quintessence, a dynamical and omnipresent field. In this case, cosmic acceleration might be temporary, so either a Big Chill or Big Crunch are possible.

Finally, if the gravitational repulsion of dark energy permanently exceeds a critical value, then the universe ends in a Big Rip. Data appears to favour scenarios that resemble a cosmological constant, but all scenarios are still in play.

Robert Caldwell is a theoretical physicist specialising in cosmology at Dartmouth College

Did you know?

Expansion means that billions of years in the future, other galaxies won't be observable.

Above: There are a few scenarios about how the universe will end

ASTROPHYSICS

Why are there no green stars?

The night sky is speckled with colour. Although most stars appear white, you will see others that are yellow, orange, red or even blue, but you will never see a star that is green. Why is that?

Stars whose peak wavelength is in green -with a wavelength of 550 nm - have a surface temperature of 5300 Kelvin, which is just a bit less than the Sun, so there are plenty of these objects. But I think the lack of green stars is a matter of human physiology, not astronomy. Our retinas do have a cone sensitive to green, but there is only a narrow band of wavelengths in which it predominates. For wavelengths a bit shorter, we see blue, while for slightly longer wavelengths we see either yellow or red. The reason why we don't see any green stars is because of the way humans perceive visible light.

Steven W. Stahler is a physics lecturer and research astrophysicist at the University of California, Berkeley

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COSMOLOGY

Does gravity behave the same throughout the cosmos?

As far as we know it does. One of the fundamental creeds of physics is that our fundamental laws of physics are independent of where you are. That does not mean that they are independent of what matter there is around you, so gravity near Earth could be different from gravity far from any matter, and it is - the curvature of space-time near Earth is different from that far away from any matter because the equations of gravity depend on the spatial distribution of matter, but the laws relating matter to gravity are the same.

Assuming the question is referring to the laws and not to the particular instantiation of those laws, could it differ? Yes, in two ways. Newton's constant, which relates gravity to the matter, could differ from place to place. That could be true in two ways. Newton's constant could change from place to place 'just because', for no reason. Or it could change from place to place because of the matter around it due to other laws relating the value of Newton's constant to the surrounding matter. The first is rejected because physics is about finding reasons for why things are as they are, but the second is an idea that a number of theorists have played with.

William Unruh is a physicist at the University of British Columbia, Vancouver

© NASA/JPL-Caltech

Left: Without gravity, everything needs to be tied down

Above: Black holes have an 'impossible' singularity at the core

COSMOLOGY

What's at the centre of a black hole?

The singularity at the centre of a black hole is the ultimate no man's land: a place where matter is compressed down to an infinitely tiny point, and all conceptions of time and space completely break down. And it doesn't really exist. Something has to replace the singularity, but we're not exactly sure what.

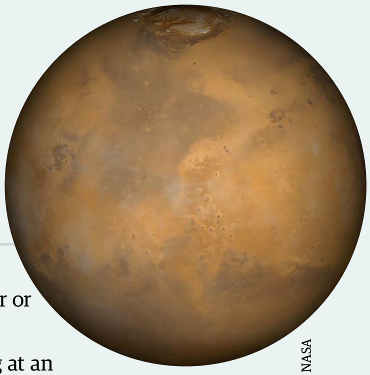
There are theoretical possibilities, though: Planck stars and gravastars. Yet maybe there's a more mundane explanation for singularities. The idea of a single point of infinite density comes from our conception of stationary, non-rotating, uncharged, rather boring black holes. Real black holes are much more interesting characters, especially when they spin.

The spin of a rotating black hole stretches the singularity into a ring. According to the math of Einstein's theory of general relativity, once you pass through the ring, you enter a wormhole and pop out through a white hole - the polar opposite of a black hole, where nothing can enter and matter rushes out at the speed of light into an entirely new and exciting patch of the universe.

Paul M. Sutter is an astrophysicist at SUNY Stony Brook and the Flatiron Institute in New York City

COSMOLOGY

What gives the planets their colours?



© NASA

The colours of the planets depend on how you look at them. With the naked eye, only the closest planets are bright enough for colours to be discernible. Mars is notoriously red because we can see through its thin, transparent atmosphere to a surface covered in rock dust that is literally rust-red, thanks to the strongly oxidising environment. When we look at Venus we see sunlight reflected off its global cloud tops, which are dazzlingly bright and white.

The outer planets - Jupiter, Saturn, Uranus and Neptune - have no solid surface, and the colour we see depends on how much atmosphere overlies permanent cloud layers. Jupiter is bright enough to see its colour with the naked eye, and compared to Mars it is distinctly yellow. A telescope will show you details of Jupiter's cloud patterns, within which there are colour variations. Some rotating storm systems, most famously Jupiter's 'Great Red Spot', are red, for reasons that we do not well understand. Suggestions include the presence of phosphorus, sulphur or organic molecules.

If you are looking at an image sent back by a spacecraft, you need to keep your wits about you. Look at the caption to find out if it is 'natural colour' or 'false colour'. The latter means that it was recorded in a different region of the spectrum to what your eyes can see, or has been subject to computer processing to make the colours more intense. In general, any image with a garish range of colours is not 'natural'. However, if you see an image of Uranus looking green or Neptune looking blue, this is real. The topmost global cloud layer of each consists of condensed methane, and is seen through a great depth of methane gas that filters out the red component of sunlight so that only green-blue light makes it down to the clouds before being reflected back.

David Rothery is professor of planetary geosciences at the Open University, UK

HUNT FOR LIFE

Has alien life ever visited Earth?

It is possible that life on Earth was seeded by space-faring, hardy microorganisms hitching a ride on rocks ejected from a planetary collision somewhere else in our Solar System - or perhaps on a planet around a distant star. This would technically make us aliens, or their biological descendants.

However, typically when we think of aliens visiting Earth, we imagine a technologically advanced space-faring civilisation travelling from some distant home world to Earth. While we have yet to discover evidence of this having happened, we are limited by the ability of alien artefacts to persist over millions of years, as well as the relative fraction of Earth's surface that has been excavated. This leaves the possibility open that aliens visited Earth millions of years ago, but then died out or decided to leave.

We also have yet to detect evidence of technological civilisations on distant exoplanets, though this is not at all surprising given how little we've actually looked. What we can say with some confidence is that there are not technologically advanced aliens here now, which by itself is somewhat surprising given the age of our galaxy and the speed with which we will likely be able to settle the galaxy.

Jonathan Carroll-Nellenback, Department of Physics and Astronomy, University of Rochester

Did you know?

It took New Horizons almost ten years to reach Pluto using a gravity assist from Jupiter.

Source: Wikipedia Commons © Public Domain

Right: The New Horizons spacecraft conducted a flyby study of Pluto in 2015

Below: This supposed UFO was photographed in Passaic, New Jersey, on 31 July 1952

SPACE EXPLORATION

What would be involved in landing humans on Pluto?

A human mission to Mars has big challenges for us in the 2020s and 2030s. By contrast, a human mission to Pluto would likely be a big challenge even a century from now. The first big challenge would be to reduce the travel time to Pluto from ten years to something like one year to make a human expedition tractable. That in turn would likely require developing either nuclear thermal or nuclear fusion drive propulsion.

We would also have to perfect a lander system designed to operate continuously in Plutonian temperatures, and to deal with the toxic gases in Pluto's atmosphere like carbon monoxide and hydrogen cyanide.

Then we would need to send ahead a robotic scouting orbiter to find safe landing sites and a robotic lander to determine the bearing strength and other properties of the candidate landing sites so that we could design the human lander. Those are all tall orders. But if they could be afforded, the scientific potential would be, well - astronomical! The field geology alone would be mouthwatering, and so would the sampling.

But perhaps best of all would be the possibility of exploring Pluto's suspected global liquid water ocean to determine if is has life or the building blocks of life.

Alan Stern is a planetary scientist at the Southwest Research Institute and principal investigator of NASA's New Horizons Mission to Pluto

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STARGAZER

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What's in the sky?

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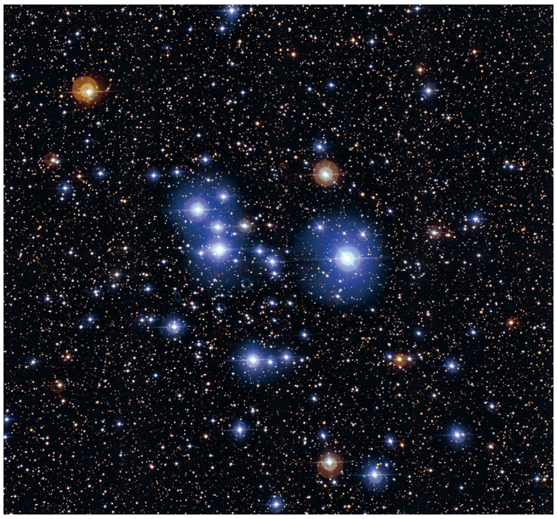
3 JAN
The Quadrantids reach their peak of 120 meteors per hour

10 JAN
Conjunction between Neptune and dwarf planet Ceres in Aquarius

14 JAN
Open star cluster Messier 47 is well placed for observation in Puppis

21 JAN
The Moon, Mars and Uranus make a close approach, within 4°38' of each other in Aries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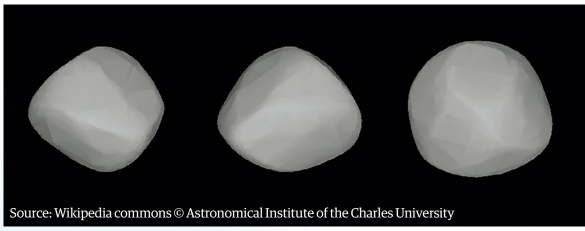
Red light friendly
In order to preserve your night vision, you should read our observing guide under red light

24 JAN
Mercury is at its greatest elongation east in the evening sky, shining brightly at -0.7


Source: Wikipedia commons © Astronomical Institute of the Charles University

14 JAN

NGC 2403 is well placed for observation in Camelopardalis, glowing at magnitude +8.9

19 JAN

The Gamma Ursae Minorid meteor shower reaches its peak of three meteors per hour

21 JAN

Conjunction between the Moon and Mars in Cetus and Aries

© ESA/Hubble

24 JAN

Asteroid 14 Irene is at opposition, glowing at magnitude +9.3 in Cancer

25 JAN

Mercury reaches dichotomy (half phase), shining at magnitude -0.5 in Capricornus

- Naked eye
- Binoculars
- Small telescope
- Medium telescope
- Large telescope

Jargon buster

Conjunction

A conjunction is an alignment of objects at the same celestial longitude. The conjunction of the Moon and the planets is determined with reference to the Sun. A planet is in conjunction with the Sun when it and Earth are aligned on opposite sides of the Sun.

Right Ascension (RA)

Right Ascension is to the sky what longitude is to the surface of the Earth, corresponding to east and west directions. It is measured in hours, minutes and seconds since, as the Earth rotates on its axis, we see different parts of the sky throughout the night.

Declination (Dec)

This tells you how high an object will rise in the sky. Like Earth's latitude, Dec measures north and south. It's measured in degrees, arcminutes and arcseconds. There are 60 arcseconds in an arcminute and there are 60 arcminutes in a degree.

Opposition

When a celestial body is in line with the Earth and Sun. During opposition, an object is visible for the whole night, rising at sunset and setting at sunrise. At this point in its orbit, the celestial object is closest to Earth, making it appear bigger and brighter.

Magnitude

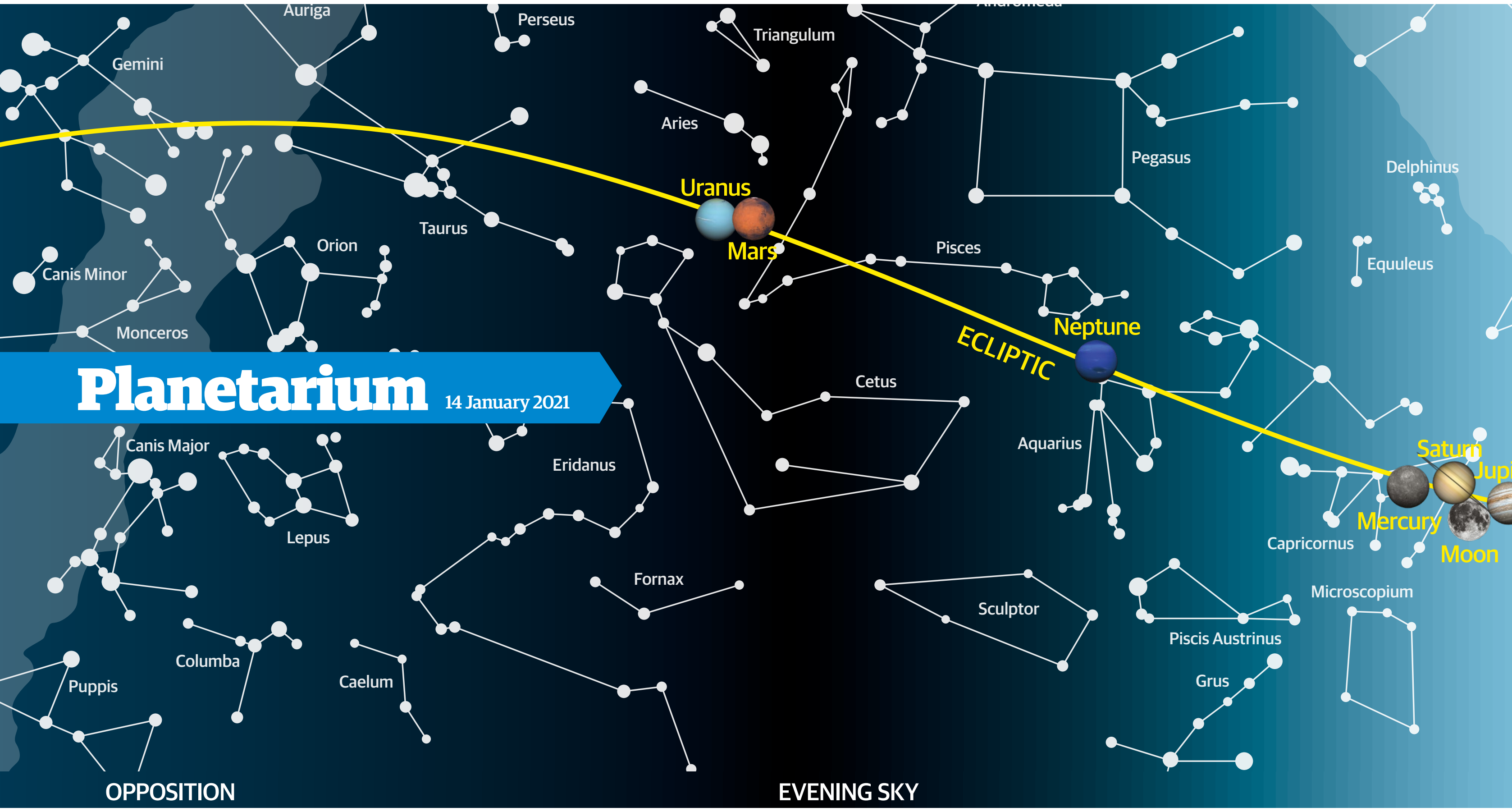
An object's magnitude tells you how bright it appears from Earth. In astronomy, magnitudes are represented on a numbered scale. The lower the number, the brighter the object. So, a magnitude of -1 is brighter than an object with a magnitude of +2.

Greatest elongation

When the inner planets, Mercury and Venus, are at their maximum distance from the Sun. During greatest elongation, the inner planets can be observed as evening stars at greatest eastern elongations and as morning stars during western elongations.

Planetarium

14 January 2021



Moon calendar

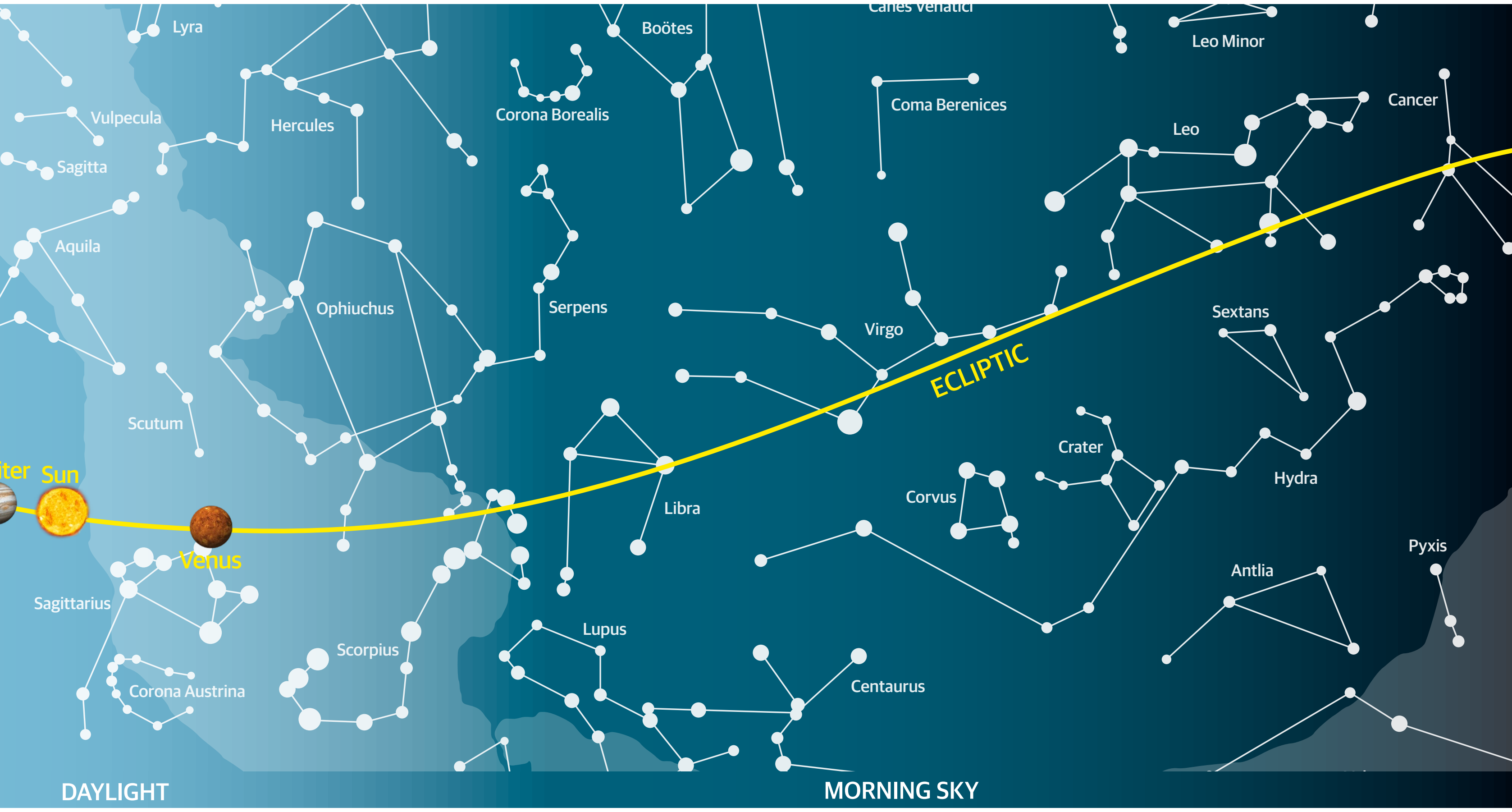
* The Moon does not pass the meridian on 28 January

31	DEC		99.1%	◒09.24	◓17.13
1	JAN		96.0%	◒10.03	◓18.26
2	JAN		90.6%	◒10.33	◓19.43
3	JAN		83.2%	◒10.57	◓21.02
4	JAN		74.0%	◒11.17	◓22.22
5	JAN		63.0%	◒11.35	◓23.42
6	JAN	LQ	51.9%	◒11.53	◓--:--
7	JAN		40.1%	◓01.04	◒12.11
8	JAN		28.8%	◓02.27	◒12.32
9	JAN		18.6%	◓03.52	◒12.58
10	JAN		10.2%	◓05.16	◒13.32
11	JAN		4.1%	◓06.35	◒14.16
12	JAN		0.7%	◓07.43	◒15.14
13	JAN	NM	0.2%	◓08.37	◒16.24
14	JAN		2.4%	◓09.17	◒17.40
15	JAN		6.9%	◓09.47	◒18.58
16	JAN		13.3%	◓10.09	◒20.13
17	JAN		21.1%	◓10.27	◒21.25
18	JAN		29.9%	◓10.43	◒22.35
19	JAN		39.2%	◓10.57	◒23.43
20	JAN	FQ	48.9%	◓11.12	◒--:--
21	JAN		58.6%	◒00.51	◓11.27
22	JAN		67.9%	◒01.59	◓11.45
23	JAN		76.7%	◒03.08	◓12.07
24	JAN		84.5%	◒04.16	◓12.34
25	JAN		91.2%	◒05.23	◓13.11
26	JAN		96.2%	◒06.25	◓13.56
27	JAN		99.2%	◒07.18	◓14.58
28	JAN	FM	--.--%*	◒08:01	◓16:09

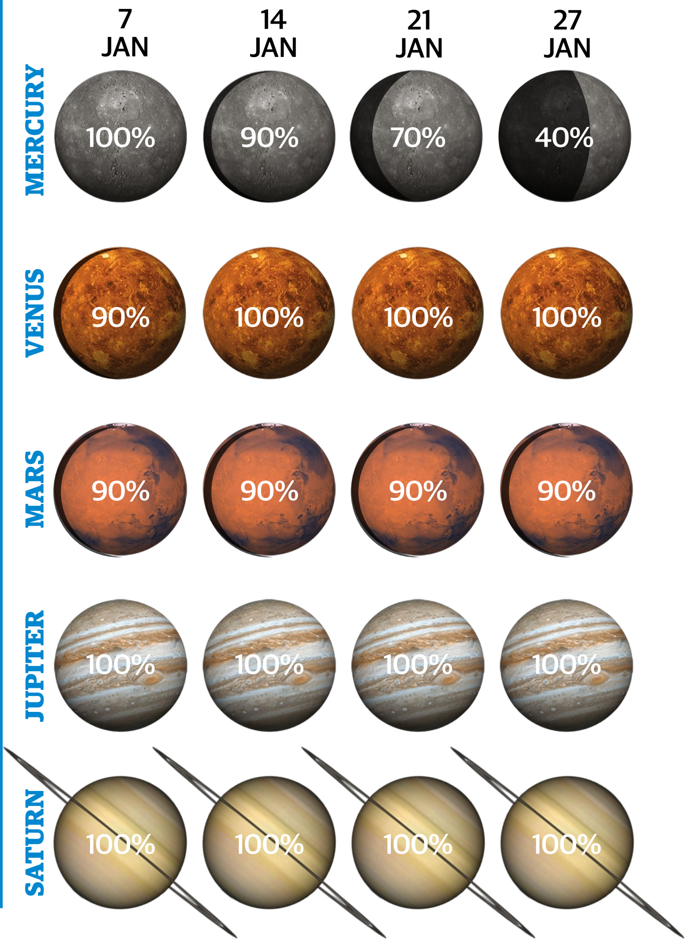
% Illumination
◓ Moonrise time
◒ Moonset time

FM Full Moon
NM New Moon
FQ First quarter
TQ Last quarter

All figures are given for 00h at midnight (local times for London, UK)



Illumination percentage



	7 JAN	14 JAN	21 JAN	27 JAN
MERCURY	100%	90%	70%	40%
VENUS	90%	100%	100%	100%
MARS	90%	90%	90%	90%
JUPITER	100%	100%	100%	100%
SATURN	100%	100%	100%	100%

Planet positions

All rise and set times are given in GMT

	Date	RA	Dec	Constellation	Mag	Rise	Set
MERCURY	31 DEC	15h 58m 02s	-24° 33' 45"	Sagittarius	-1.0	08:45	16:14
	7 JAN	19h 59m 03s	-22° 46' 57"	Sagittarius	-0.9	08:54	16:48
	14 JAN	20h 46m 12s	-19° 46' 10"	Capricornus	-0.9	08.54	17.27
	21 JAN	21h 26m 33s	-15° 50' 31"	Capricornus	-0.8	08:43	18:04
	27 JAN	21h 48m 14s	-12° 33' 12"	Capricornus	-0.3	08:22	18:20
VENUS	31 DEC	17h 11m 53s	-22° 16' 27"	Ophiuchus	-3.9	06:31	14:32
	7 JAN	17h 49m 46s	-23° 00' 36"	Sagittarius	-3.9	06:47	14:38
	14 JAN	18h 27m 57s	-23° 10' 29"	Sagittarius	-3.9	06:58	14:47
	21 JAN	19h 06m 04s	-22° 45' 32"	Sagittarius	-3.9	07:06	15:00
	27 JAN	19h 38m 25s	-21° 56' 56"	Sagittarius	-3.9	07:09	15:15
MARS	31 DEC	01h 37m 36s	+11° 04' 01"	Pisces	-0.3	11:55	02:01
	7 JAN	01h 49m 14s	+12° 17' 51"	Aries	-0.1	11:33	01:52
	14 JAN	02h 01m 48s	+13° 32' 55"	Aries	+0.1	11:11	01:44
	21 JAN	02h 15m 11s	+14° 48' 13"	Aries	+0.2	10:49	01:37
	27 JAN	02h 27m 13s	+15° 52' 05"	Aries	+0.3	10:32	01:31
JUPITER	31 DEC	20h 18m 37s	-20° 07' 37"	Capricornus	-2.0	09:23	17:53
	7 JAN	20h 25m 17s	-19° 45' 46"	Capricornus	-1.9	09:00	17:34
	14 JAN	20h 32m 02s	-19° 22' 41"	Capricornus	-1.9	08:37	17:16
	21 JAN	20h 38m 48s	-18° 58' 28"	Capricornus	-1.9	08:14	16:57
	27 JAN	20h 44m 37s	-18° 36' 55"	Capricornus	-1.9	07:54	16:42
SATURN	31 DEC	20h 44m 37s	-18° 36' 55"	Capricornus	+0.6	09:20	17:47
	7 JAN	20h 17m 32s	-20° 05' 20"	Capricornus	+0.6	08:55	17:24
	14 JAN	20h 20m 57s	-19° 54' 35"	Capricornus	+0.6	08:29	17:01
	21 JAN	20h 24m 23s	-19° 43' 29"	Capricornus	+0.6	08:03	16:38
	27 JAN	20h 27m 20s	-19° 33' 46"	Capricornus	+0.6	07:42	16:19

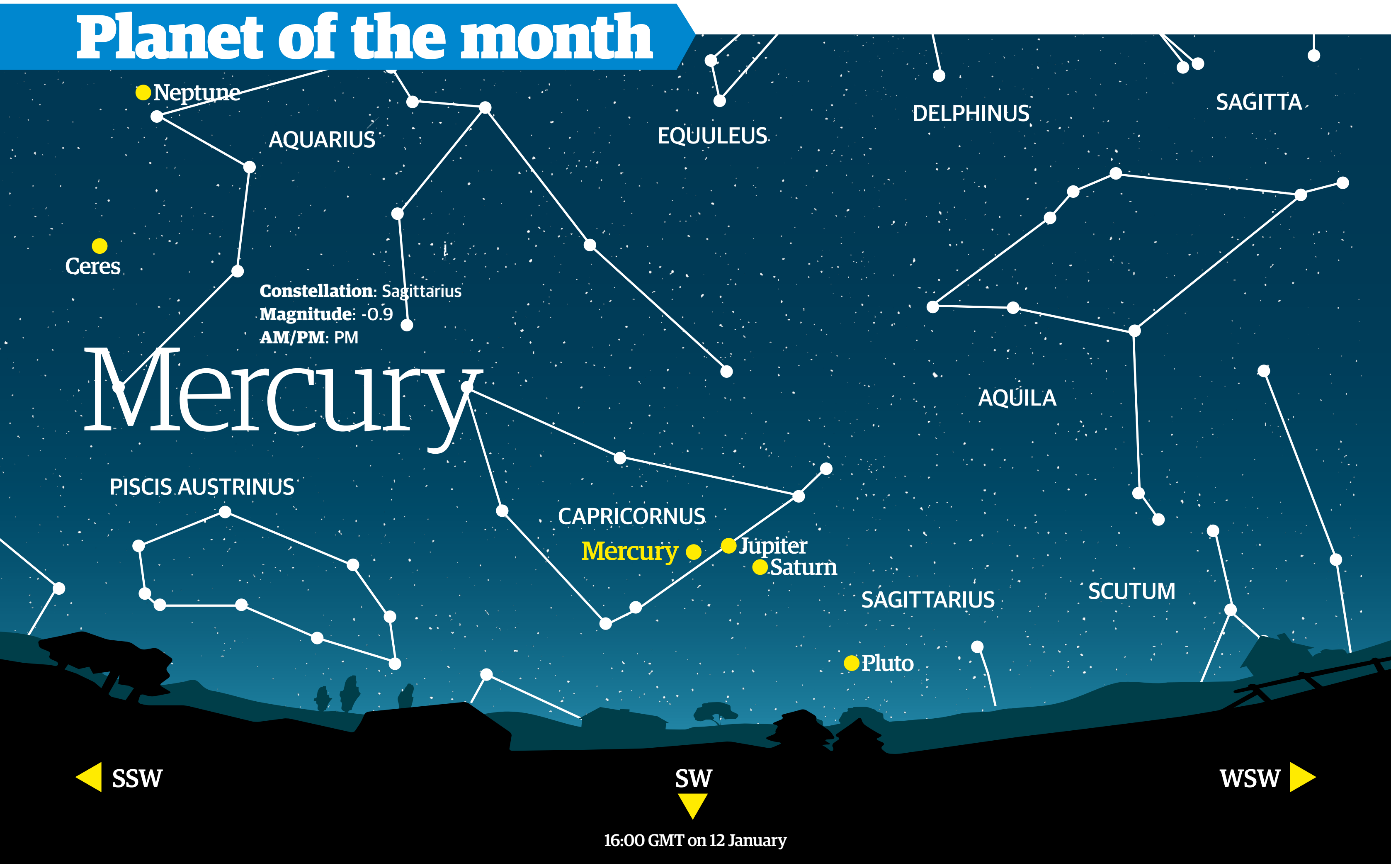
This month's planets

Mercury will glide past Jupiter and Saturn, which remain close together after their great conjunction last year

Planet of the month

Mercury

Constellation: Sagittarius
Magnitude: -0.9
AM/PM: PM



16:00 GMT on 12 January

Our Planet of the Month for January is the smallest planet of them all: Mercury, the closest world to the Sun. As Mercury is the nearest planet to the Sun it never strays far from it in the sky. We never see it shining brightly in a dark sky, only for a short time after sunset or before sunrise.

Because of this proximity, many people - even amateur astronomers - have never seen this fascinating world, but by mid-month it will be very well placed for observation by everyone, looking like a copper-coloured star low in the southwest after sunset.

The good news is that although Mercury will be too close to the Sun to be seen at the very start of the month, as January progresses Mercury will get easier to see as it climbs higher in the twilight sky and further away from the Sun.

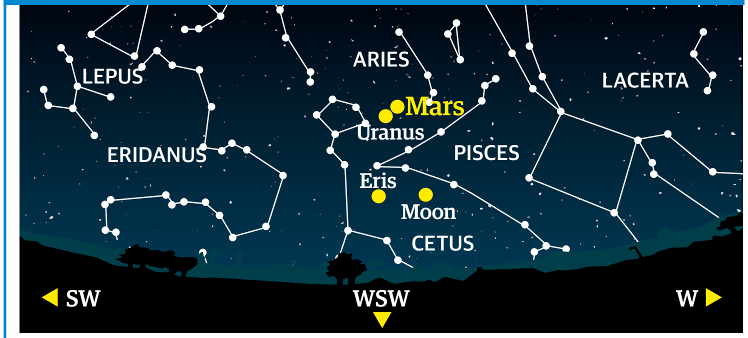
Even better is Mercury's creeping flyby of Jupiter and Saturn. Between 8 and 12 January it will glide up towards and then pass these two worlds, which are still shining very close together in the sky after sunset. A word of caution though: this planetary gathering will be taking place low in the bright twilight sky soon after sunset, so you must wait until the Sun has set before you try to see it through your binoculars or telescope.

On 8 January Mercury will be visible to the lower right of Saturn, and the following evening will be almost directly beneath it. Cross your fingers for very clear skies on the evening of 10 January, because that's when Mercury will form a perfect triangle with Jupiter and Saturn, each world only two degrees - or four Moon widths - or so from the others. By 14 January Mercury will have overtaken both Jupiter and Saturn and will be higher than both of the gas giants in the southwest as twilight deepens.

By the end of the month Mercury will be at its best, setting almost two hours after the Sun and visible in the southwest after sunset as a copper-hued spark of light in the twilight. If your eyes can't spot it right away, sweep the sky with binoculars to pin down its location. Once you've seen where it is in relation to landmarks on your horizon, your eyes will go right to it.

This month's planets

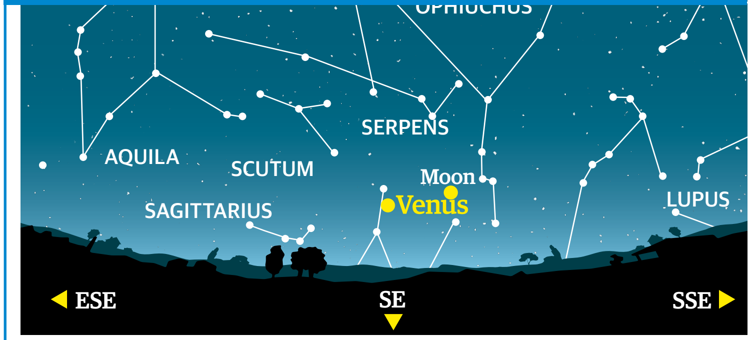
Mars 22:00 GMT on 19 January



Constellation: Pisces
Magnitude: -0.3
AM/PM: PM

The Red Planet - which actually looks more orange than red to the naked eye - will be visible in the evening sky all through this month. It will already be shining high in the southeast as darkness falls and will be visible right through until the early hours of the morning, at its highest in the south around 19:00.

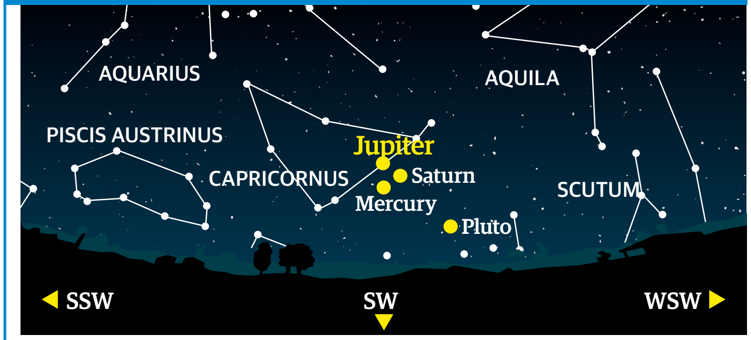
Venus 08:00 GMT on 11 January



Constellation: Ophiuchus
Magnitude: -3.9
AM/PM: AM

Venus is a prominent 'morning star' at the start of our observing period, immediately noticeable as a strikingly bright naked-eye object low in the southeast well before sunrise, but as the month progresses it will get closer and closer to the Sun until it becomes lost in its glare by mid-month.

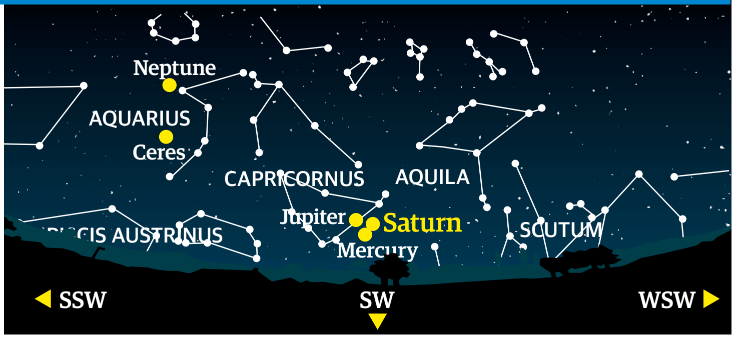
Jupiter 16:00 GMT on 10 January



Constellation: Capricornus
Magnitude: -2.1
AM/PM: PM

Jupiter is an evening object during January, but will only be visible for a short time after sunset, low in the southwest, before setting. Following its close encounter with Saturn last month, Jupiter is now pulling away from it, but the two worlds remain close during January, starting the month just a degree apart.

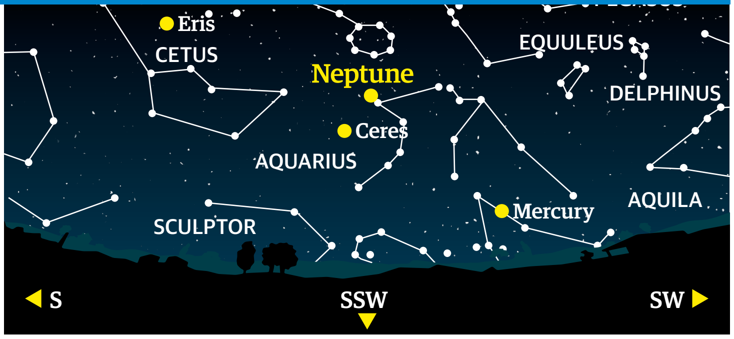
Saturn 16:00 GMT on 10 January



Constellation: Capricornus
Magnitude: +0.6
AM/PM: PM

Saturn will be visible in the evening sky during the first half of our observing period, low in the southwest as soon as the Sun sets, but you'll only have a short window to see it in. It will lie to the lower right of much brighter Jupiter, so close that the two worlds will look like a striking double star.

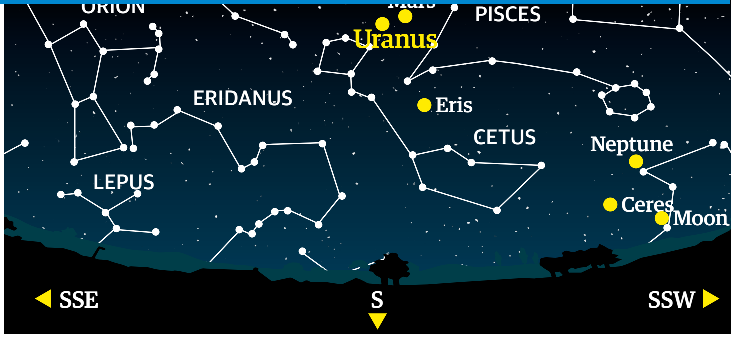
Neptune 17:00 GMT on 20 January



Constellation: Aquarius
Magnitude: +7.9
AM/PM: PM

Neptune - the most distant planet in our Solar System - is an evening object this month, located roughly halfway between orange-red Mars and the close pair of Jupiter and Saturn, but shining at only magnitude +7.9 you'll need a pair of binoculars or a telescope to pick it out from the background stars.

Uranus 19:00 GMT on 16 January



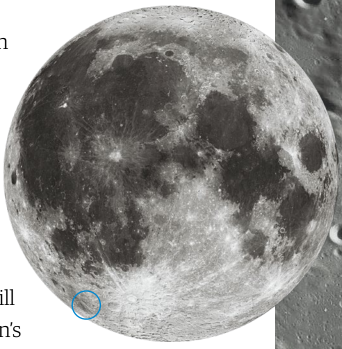
Constellation: Aries
Magnitude: +5.7
AM/PM: PM

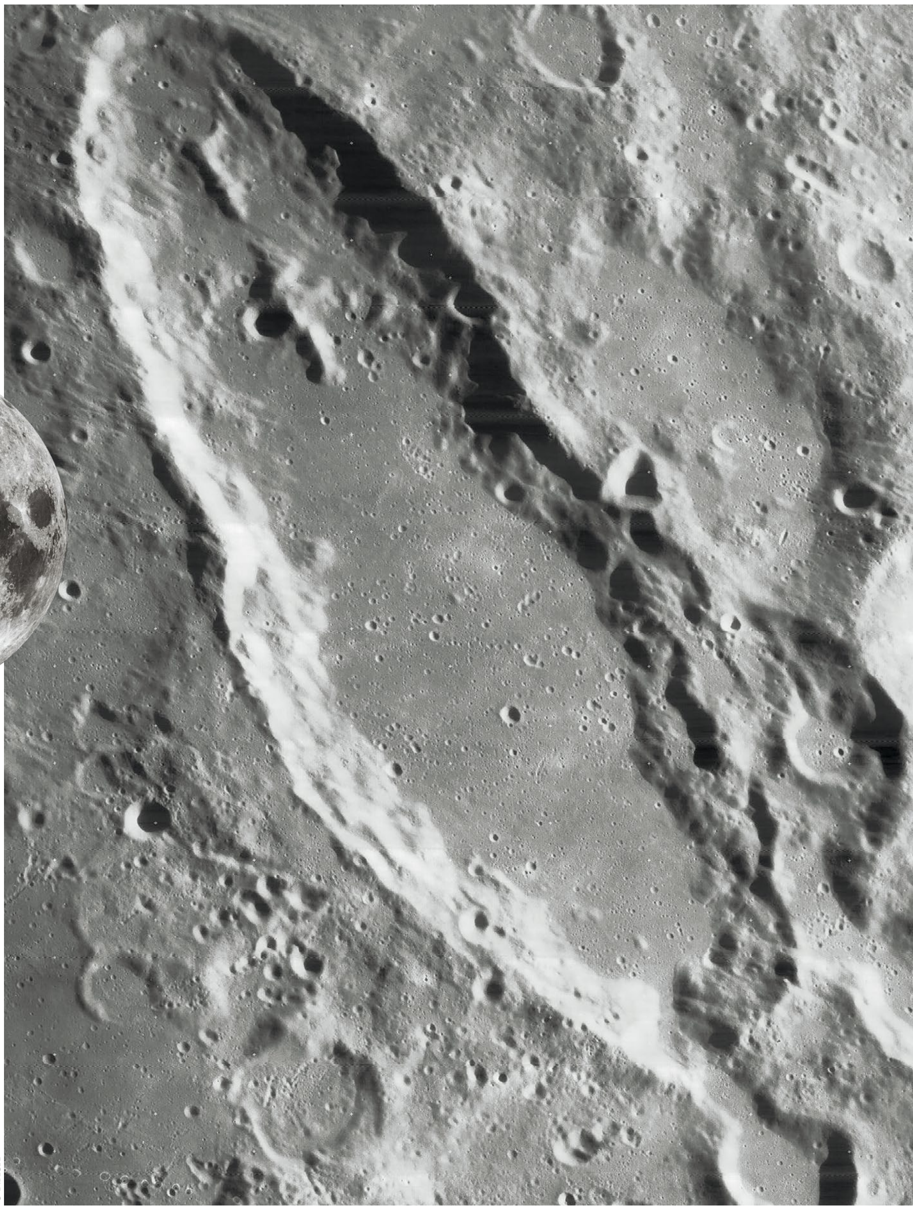
Uranus is technically visible to the naked eye, but you'll only be able to spot it that way if you know exactly which star-like point it is in an area of stars of the same brightness. A pair of binoculars will help you identify it from its pale-green colour. Uranus hugs close to much brighter Mars throughout January.

Moon tour

Schiller

To start off the New Year, spot one of the strangest-shaped craters on the Moon





© NASA

Top tip!

As with all features on the Moon, your best views of Schiller will be on evenings when it is close to the terminator and illuminated from a low angle.

Ask a child to draw a picture of the Moon with craters, and those craters will be round. They probably were when you drew them at school, too. That's also how we see the Moon's largest craters through binoculars and telescopes – round holes blasted out of its rocky surface millions or even billions of years ago by chunks of space rock – and an internet search for 'lunar craters' will quickly fill your screen with stunning photos of the Moon's rugged surface pockmarked and scattershot with round craters. But dig a little deeper, stray from the well-trodden tourist path that takes in all the famous craters and you'll find a handful of lunar craters that aren't round. In fact, they're downright strange.

Down in the southern lunar highlands, forming a neat triangle with the bright, famously ray-splashed crater Tycho and the huge walled plain Clavius – which you may recall was in the headlines late in 2020 after the discovery of water-bearing glass beads on its sunlit slopes – Schiller is a 179-kilometre (111-mile) long, 71-kilometre (44-mile) wide impact feature. It might not be one of the Moon's best known, A-list craters, but is a quiet favourite among experienced Moon observers.

Through a small telescope the crater looks more like a short, lozenge-shaped valley than a more typical round or oval crater. This is because being so close to the Moon's limb and far south, we see Schiller at an oblique angle, which makes it appear foreshortened. Views taken from above during the Apollo missions, or more recently by surveying orbiters, show Schiller is an elongated feature, often described as 'lozenge-shaped' by experienced lunar observers, while others think it looks more like a slug or even a leech.

Schiller isn't unique, however. Elsewhere in the Solar System other worlds have craters that refuse to conform. On Venus is a 120-kilometre (75-mile) long crater called 'Graham' which looks like a tadpole, while 'Orcus Patera', a 388-kilometre (241-mile) wide crater gouged out of the ruddy surface of Mars, is shaped like a wine bottle.

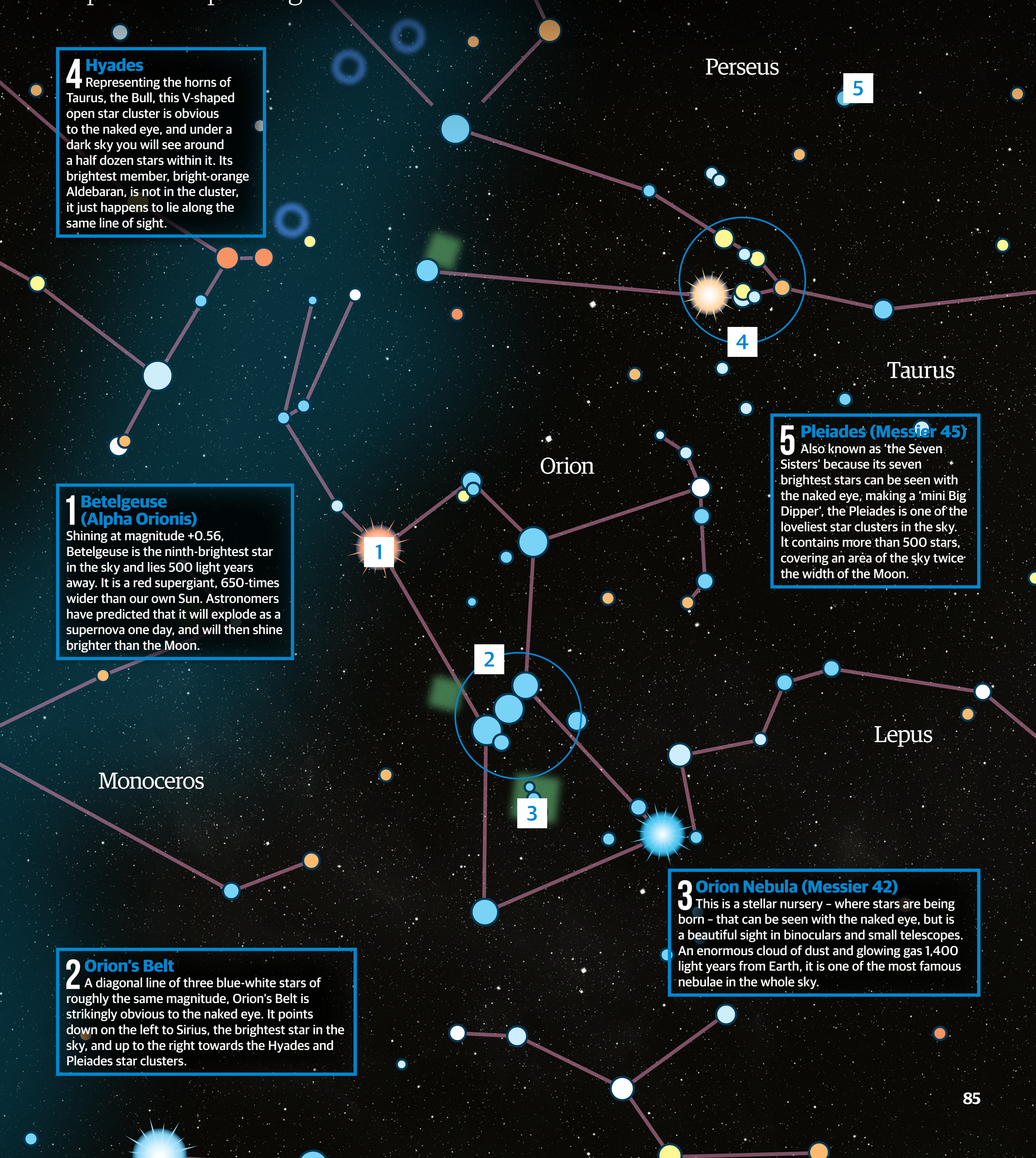
What causes these weird shapes? It seems likely that they are the result of impacting bodies coming in at shallow angles, striking the surface at a skid, or a roll, rather than from above. The result is a long scar, more like a trough than a round hole. In Schiller's case it's a little more complicated. At first glance, especially at low magnification, it's easy to think that it was made when a single chunk of space debris struck the Moon, ploughing a long scar out of its surface. However, seen from directly above Schiller is revealed to be not just one, but two craters, which formed when multiple meteoroids, perhaps as many as four, slammed into the Moon almost simultaneously.

Look at Schiller through your telescope's highest magnification eyepiece and you'll be amazed by how much detail you can see in and around it. Its rim will appear sharp and well-defined. Within that rim, on Schiller's walls, which rise around four kilometres (2.5 miles) from its floor, you'll see many different terraces, shelves and ledges. You'll also see two low ridges protruding from its floor on the western end, while the eastern floor will look much flatter and smoother. A few small craterlets can be seen spattered across the crater floor too. So when is the best time to see this fascinating crater this month?

On New Year's Eve the Moon will be visible all through the night, but just past full, so Schiller will be hard to see, bleached out by bright overhead sunlight. It should start to pop into view around 7 January, as the terminator, the line between lunar day and night, begins to sweep towards it. By 8 January Schiller's walls will cast stark shadows, making it stand out in an eyepiece. The best view will be on the evening of 8 January, when the crater will be illuminated from a very low angle. By 10 January Schiller will have been plunged into darkness, and it will remain in darkness until 25 January, when it will be bathed in sunlight once more.

Naked eye & binocular targets

Explore the sparkling winter wonders in and around Orion



4 Hyades

Representing the horns of Taurus, the Bull, this V-shaped open star cluster is obvious to the naked eye, and under a dark sky you will see around a half dozen stars within it. Its brightest member, bright-orange Aldebaran, is not in the cluster, it just happens to lie along the same line of sight.

1 Betelgeuse (Alpha Orionis)

Shining at magnitude +0.56, Betelgeuse is the ninth-brightest star in the sky and lies 500 light years away. It is a red supergiant, 650-times wider than our own Sun. Astronomers have predicted that it will explode as a supernova one day, and will then shine brighter than the Moon.

5 Pleiades (Messier 45)

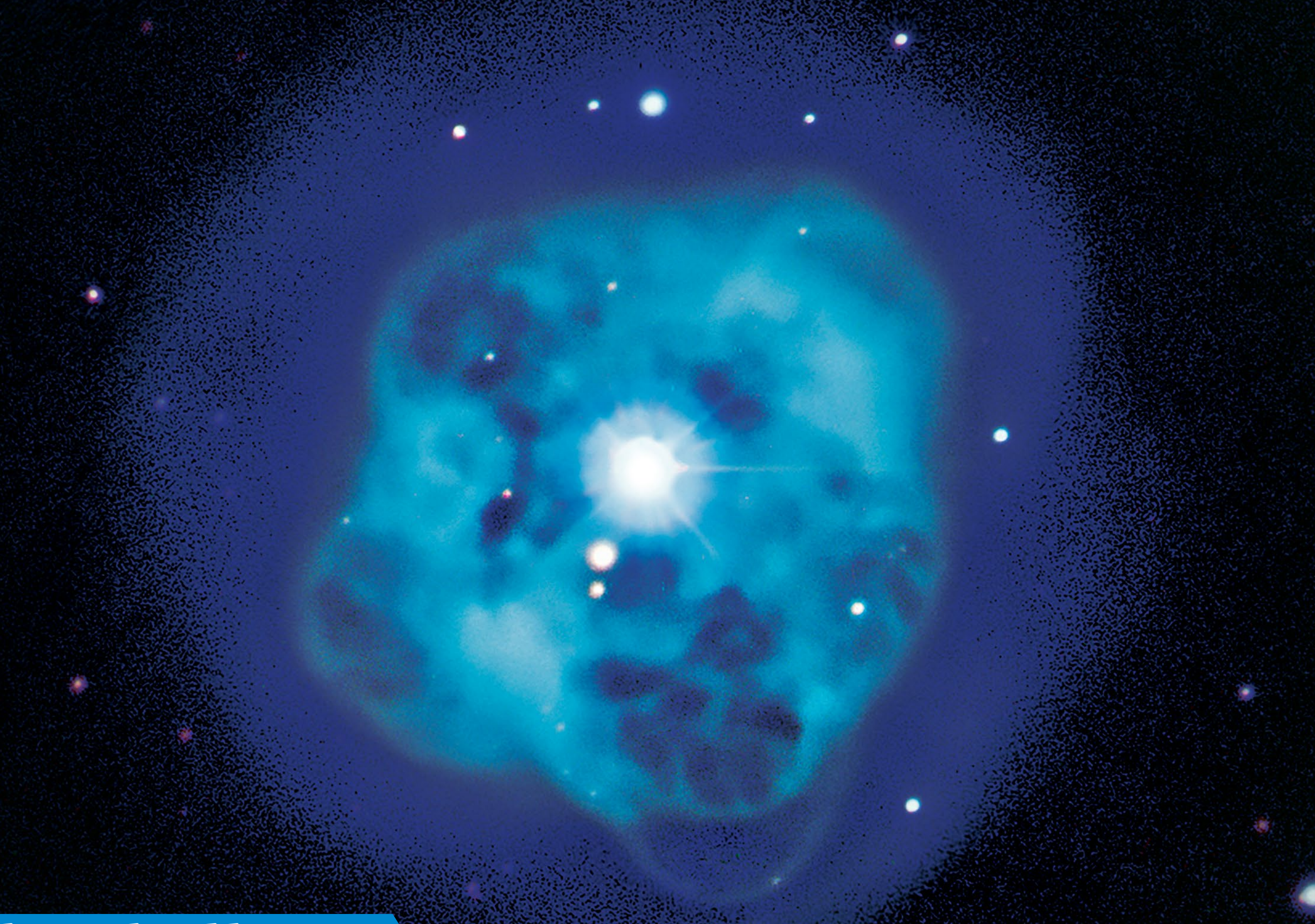
Also known as 'the Seven Sisters' because its seven brightest stars can be seen with the naked eye, making a 'mini Big Dipper', the Pleiades is one of the loveliest star clusters in the sky. It contains more than 500 stars, covering an area of the sky twice the width of the Moon.

3 Orion Nebula (Messier 42)

This is a stellar nursery – where stars are being born – that can be seen with the naked eye, but is a beautiful sight in binoculars and small telescopes. An enormous cloud of dust and glowing gas 1,400 light years from Earth, it is one of the most famous nebulae in the whole sky.

2 Orion's Belt

A diagonal line of three blue-white stars of roughly the same magnitude, Orion's Belt is strikingly obvious to the naked eye. It points down on the left to Sirius, the brightest star in the sky, and up to the right towards the Hyades and Pleiades star clusters.



Crystal Ball Nebula
(NGC 1514)

Source: Wikipedia Commons © Göran Nilsson & The Liverpool Telescope

Deep sky challenge

Little-known treasures of Taurus

There's more to the Bull than the Hyades and Pleiades star clusters – just look a little deeper

On frosty January nights, Taurus' glittering Hyades and Pleiades star clusters, two of the most famous and beloved deep-sky objects in the whole of the sky, demand attention. Peering into their telescopes, clapping their hands together for warmth, many deep-sky observers are happy just to gaze at the picture-perfect pair through their telescopes, ignoring the rest of the sky. But if you take a moment to look away from them, there are plenty of other fascinating things to look at around those two famous clusters.

The supernova remnant of the Crab Nebula (Messier 1) is a popular target for deep-sky observers throughout the winter months, even if it bears only a passing resemblance to the scuttling creature it is named after and is a lot fainter and more challenging to see than many inexperienced observers expect when they look for it for the first time.

Lurking between the sharp horns of the Bull is NGC 1615, a faint but pretty galaxy, close to a little-known open star cluster known as the Pirate Moon Cluster. The Crystal Ball Nebula, a planetary nebula would be much more popular if it wasn't overshadowed by the sparkling haze of the nearby Seven Sisters (Messier 45).

NGC 1746

Source: Wikipedia Commons © Egres73

1 NGC 1807 and NGC 1817

Nicknamed 'the Poor Man's Double Cluster', this neighbouring pair of scattered open star clusters is technically bright enough to be seen in binoculars, but a telescope's wide-field eyepiece gives by far the best views.

2 The Crab Nebula (Messier 1)

You'll need a medium-aperture telescope, high magnification and dark skies to see the delicate, wispy structure in the outer regions of this famous eighth-magnitude supernova remnant.

3 NGC 1647

Some 1,800 light years away, the Pirate Moon Cluster is a +6.5 irregular spray of colourful stars that is overshadowed by the nearby Pleiades. A medium-power eyepiece reveals the cluster's faint outer members.

4 NGC 1615

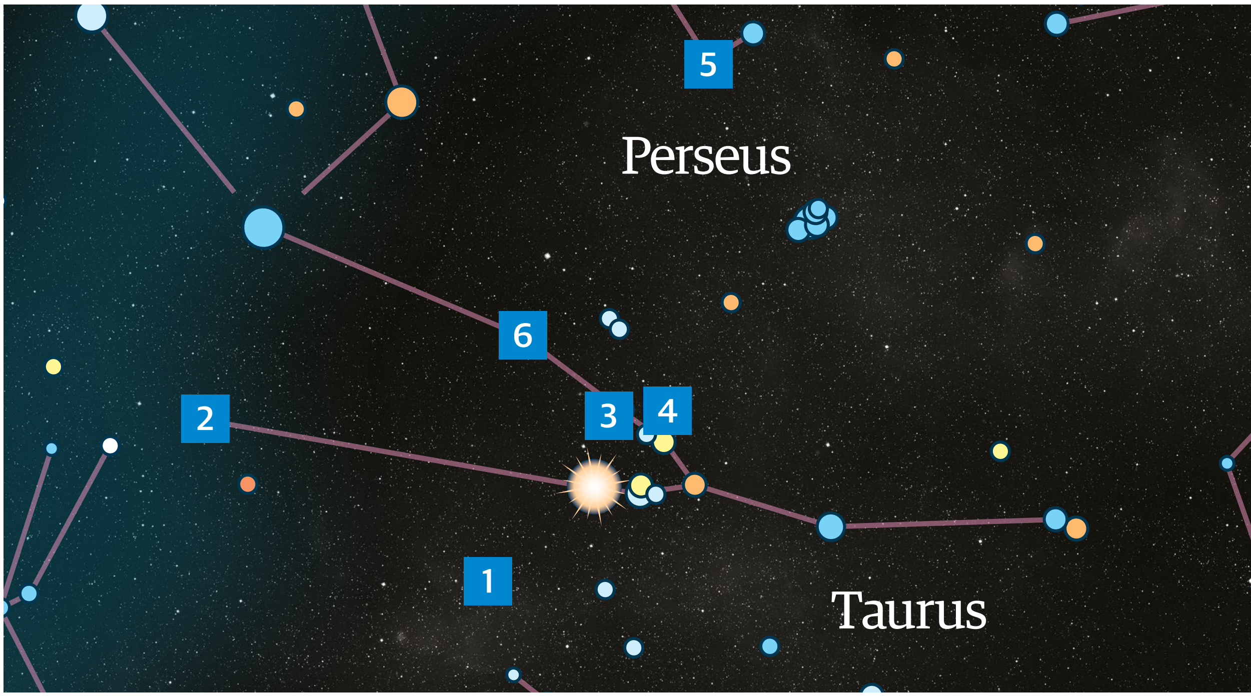
Views of this 11th-magnitude elliptical galaxy, 159 million light years from Earth, are reserved for large-aperture telescopes on nights of excellent seeing. Even then it is just a small, irregular smudge, however.

5 NGC 1514

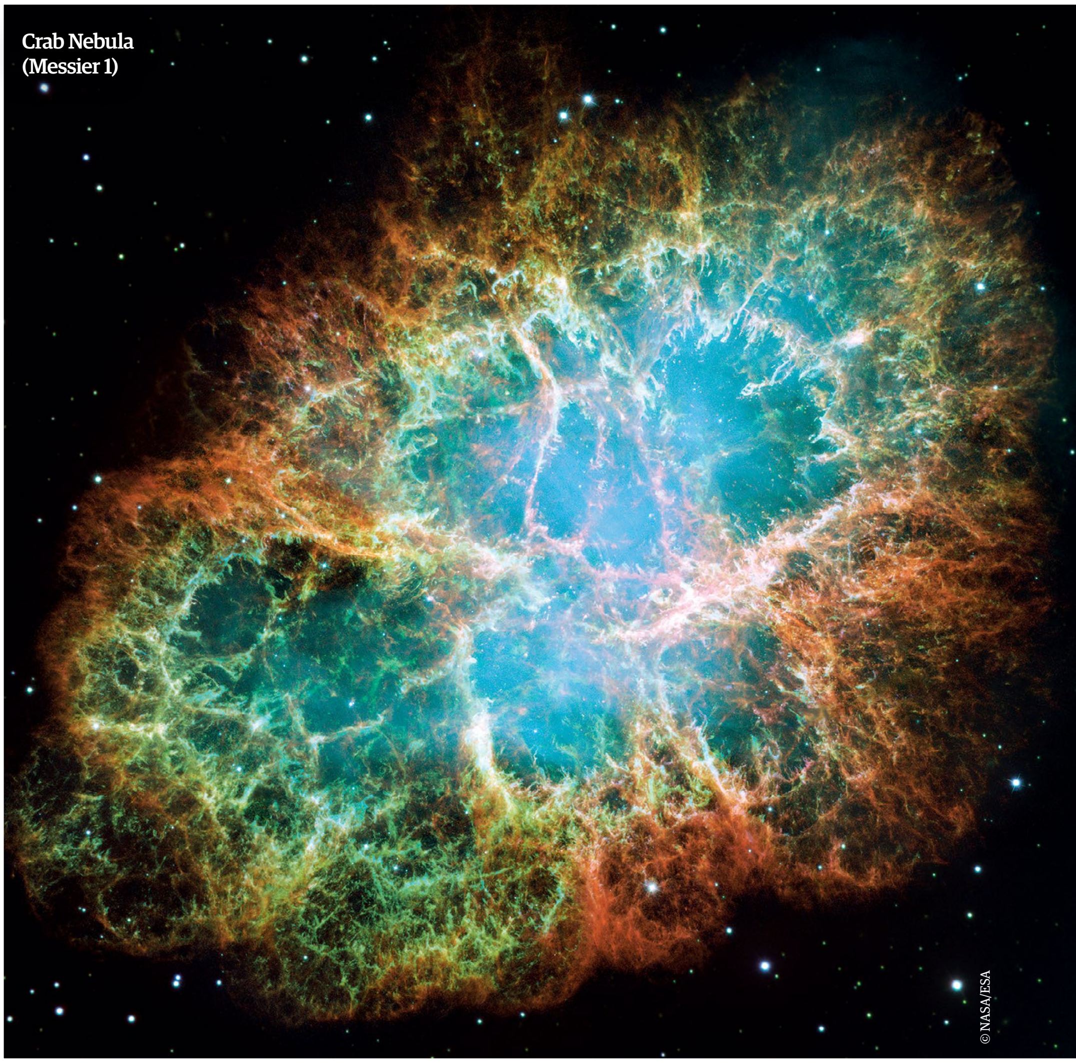
This tenth-magnitude planetary nebula is known as the Crystal Ball Nebula because of the pretty and delicate structures and mottling within it, but you'll need a large telescope and a high-power eyepiece to see them.

6 NGC 1746

Roughly 2,600 light years away, this open cluster contains around 20 stars, spread thinly over a wide area. Its low surface brightness means you'll need good seeing and a medium-aperture telescope to see all its members properly.



> "THERE ARE PLENTY OF OTHER FASCINATING THINGS TO LOOK AT AROUND THOSE TWO FAMOUS CLUSTERS"


Crab Nebula (Messier 1)

© NASA/ESA

The Northern Hemisphere

Get stuck into a plethora of galaxies, nebulae and star clusters

Winter offers a selection of targets not just for the beginner to whet their stargazing appetite, but for seasoned sky-watchers to get truly stuck into a tour of the heavens. Mid-January through to February offers a selection of star clusters, galaxies and nebulae for those armed with or without an optical aid. These views compliment the readily available planets, which observers will see make their grand appearances at dusk and dawn through the coming weeks. A selection of galaxies, including the Cigar Galaxy (Messier 82) bursting with star formation in the constellation of Ursa Major, as well as Messier 106, Messier 94 and Messier 63 in Canes Venatici, and the star clusters of Gemini, Orion and Perseus, are also viewing delights.

Using the sky chart

This chart is for use at 22:00 (GMT) mid-month and is set for 52° latitude.

01 Hold the chart above your head with the bottom of the page in front of you.

02 Face south and notice that north on the chart is behind you.

03 The constellations on the chart should now match what you see in the sky.

Magnitudes

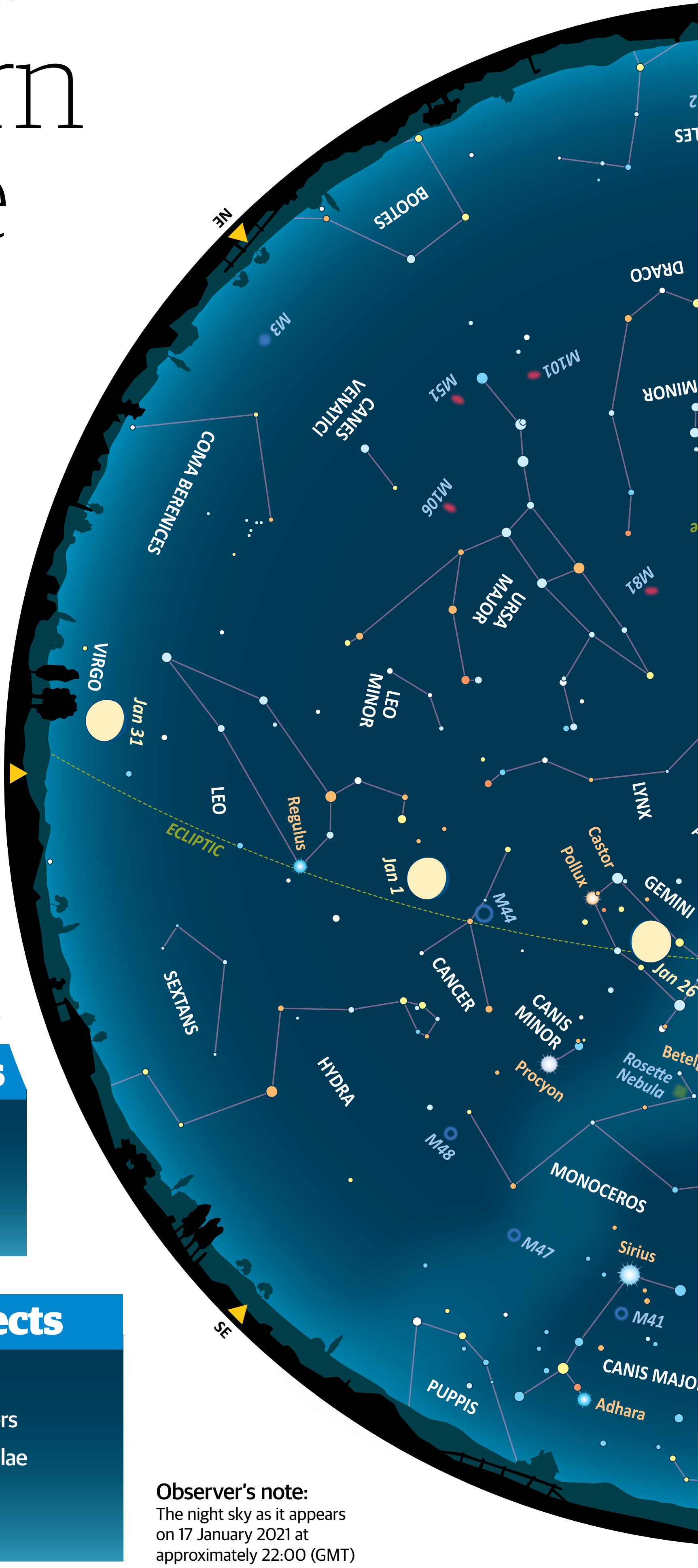
- Sirius (-1.4)
- -0.5 to 0.0
- 0.0 to 0.5
- 0.5 to 1.0
- 1.0 to 1.5
- 1.5 to 2.0
- 2.0 to 2.5
- 2.5 to 3.0
- 3.0 to 3.5
- 3.5 to 4.0
- 4.0 to 4.5
- Fainter
- Variable star

Spectral types

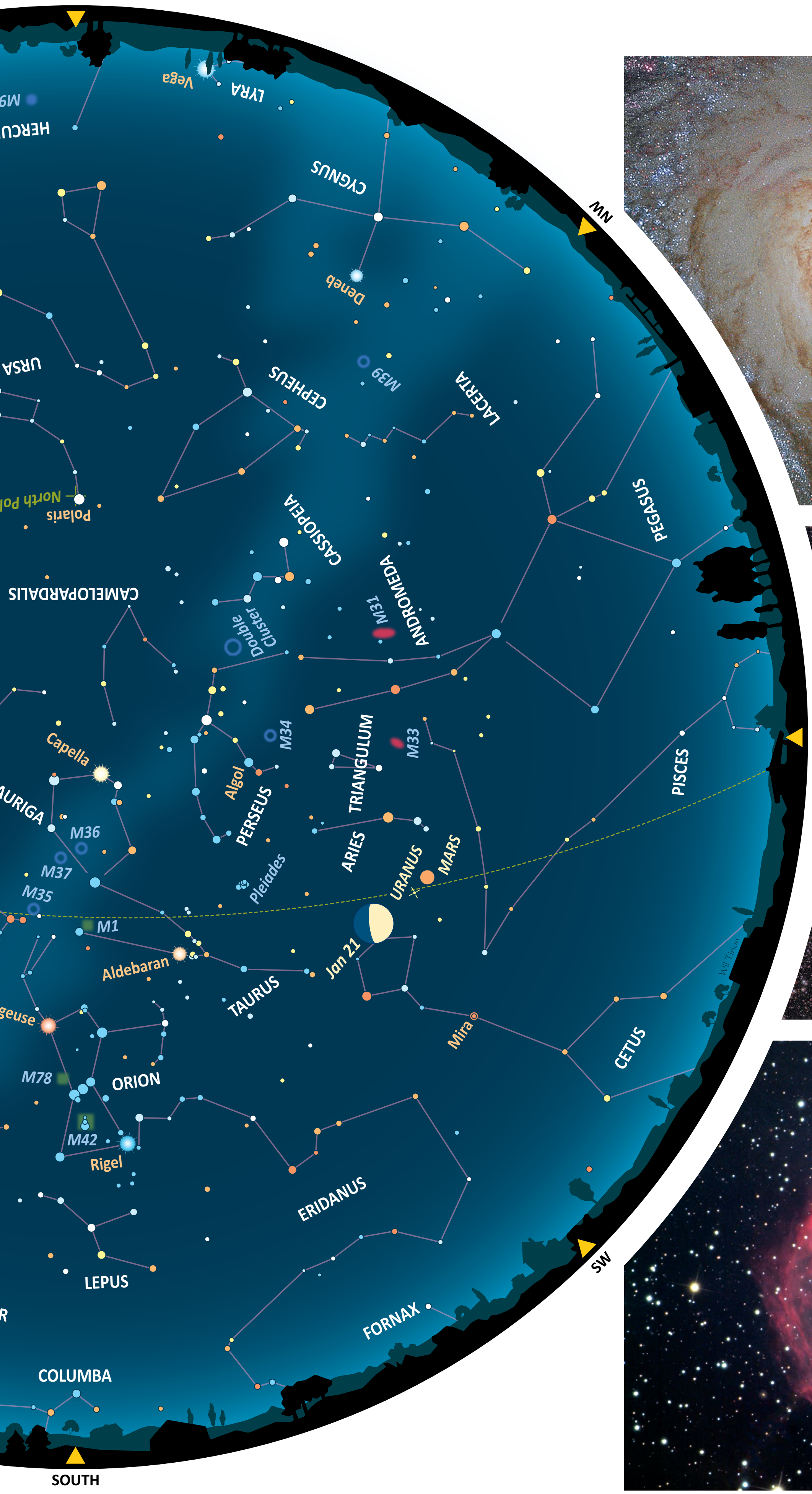
- O-B
- A
- F
- G
- K
- M

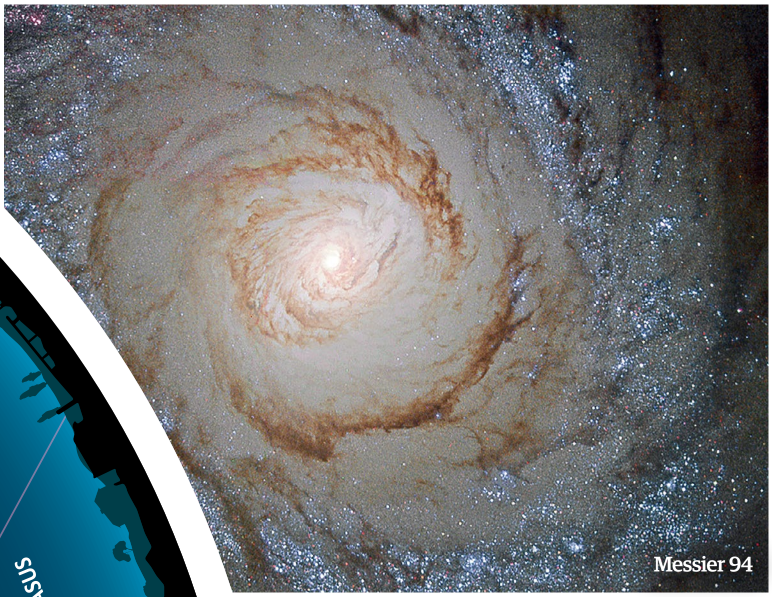
Deep-sky objects

- Open star clusters
- Globular star clusters
- Bright diffuse nebulae
- Planetary nebulae
- Galaxies



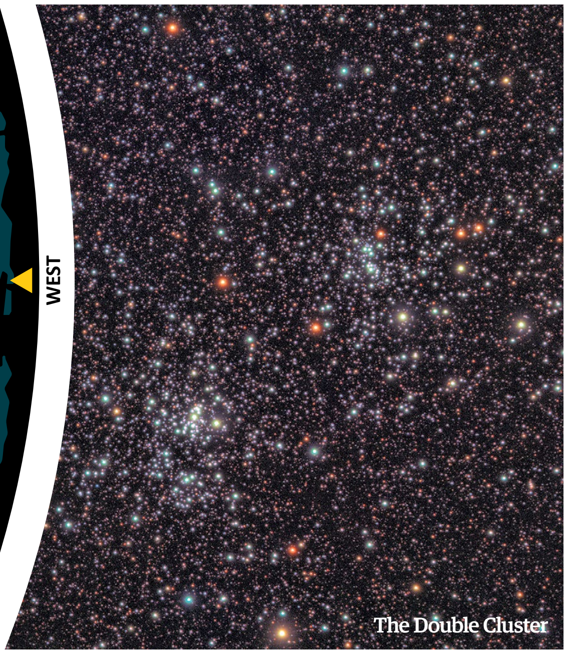
Observer's note:
The night sky as it appears on 17 January 2021 at approximately 22:00 (GMT)





Messier 94

© ESA/Hubble & NASA



The Double Cluster

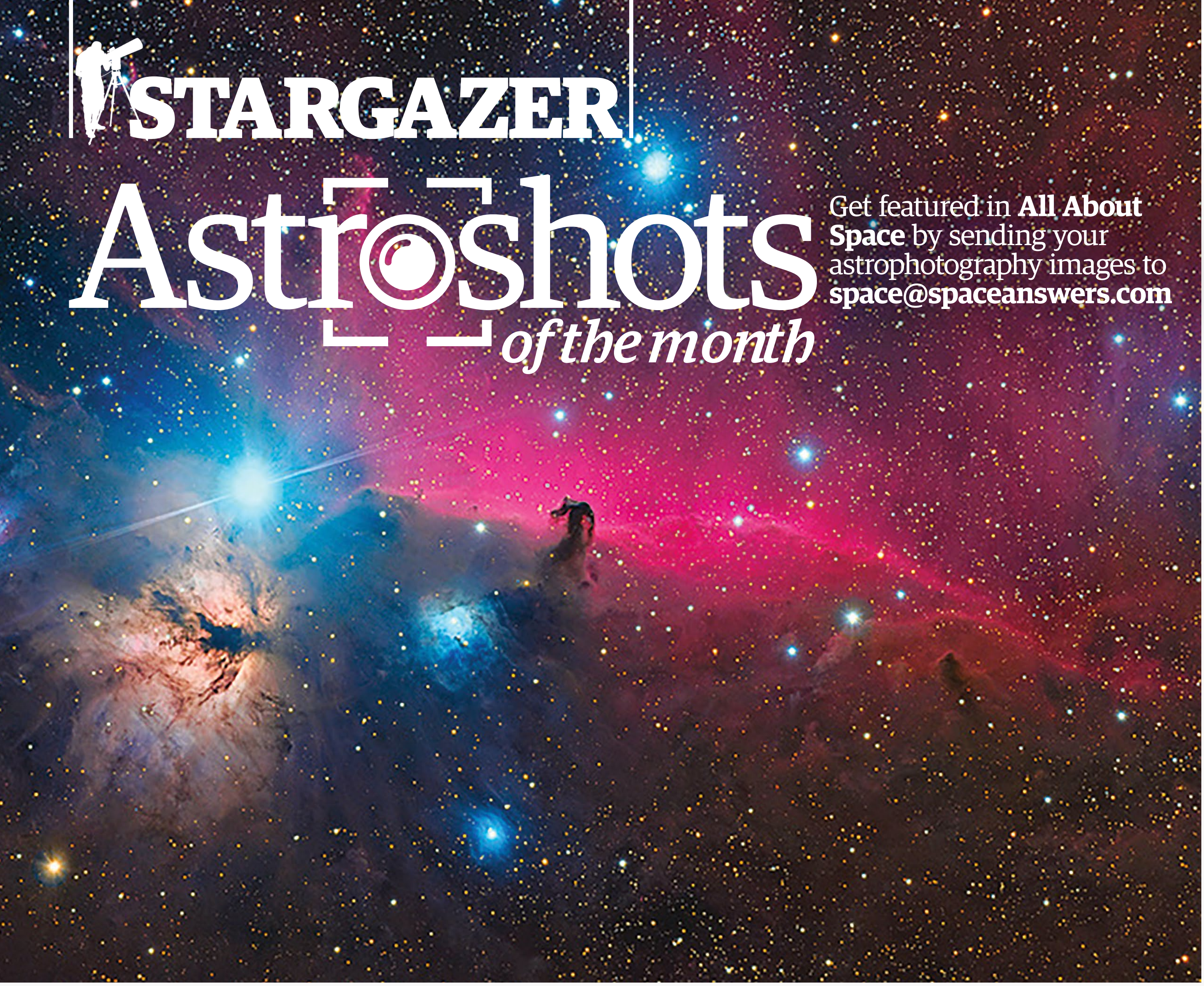
Source: Wikipedia Commons © Chrisguidry

Medusa Nebula (Abell 21)

Source: Wikipedia Commons © Jschulman555

Astroshots of the month

Get featured in **All About Space** by sending your astrophotography images to **space@spaceanswers.com**



Warren Keller

Location: West Virginia, US

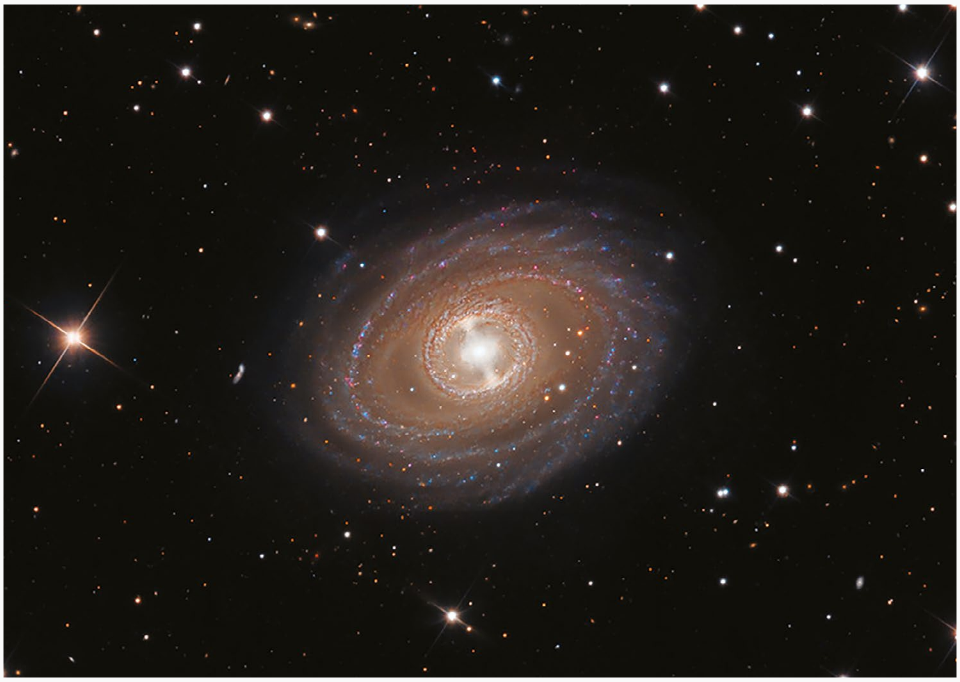
Telescope: 16-inch RCOS Ritchey-Chrétien owned by the University of North Carolina

"A child of the 1960s – *Star Trek*, *2001: A Space Odyssey* – I boldly went with my heroes 'where no man [had] gone before', and I never really touched down again. I began exploring the night sky at 15 with an eight-inch Newtonian and I knew I would someday photograph the wonders of the heavens.

"I started out using film in 1998, and then I switched to a charged-coupled device (CCD) in 2003. I am artistic by nature, so it's less about the cosmology and more about the thrill of the hunt for the myriad beautiful shapes and colours evident throughout the universe."

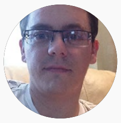
Above: The Horsehead Nebula (Barnard 33)

Right: Flocculent galaxy NGC 1398



Johnny Rowe

Location: Belper, Derbyshire



Telescope: Sky-Watcher ST80 and Celestron NexStar 80GTL

"I imaged the Milky Way using my Canon 1100D from my local dark spot in Alport Heights. I was really pleased with how this image turned out, as it's the first Milky Way picture that I've managed to take showing some of the colours of our galaxy.

"I am also very pleased with how my Moon image turned out since it was the first time I've actually managed to successfully stack a picture using the Registax astrophotography software. Now that the dark nights are drawing in, I'm hoping to image a few more objects. Recently I snapped the Triangulum Galaxy (Messier 33)."

Above: The Milky Way

Left: Triangulum Galaxy (Messier 33)

Right: The Moon

Terry Hancock

Location: Michigan, US

Telescope: 12" Ritchey-Chrétien reflector and Takahashi E180 Astrograph

"My interest in astronomy and photography began some 40 years ago in Australia. Inspired by the late Sir Patrick Moore, my first telescope was a 4.5-inch Newtonian. I enjoyed many nights in the pollution-free, dark southern night skies of the hot Australian outback. It was often so dark that the Milky Way cast a shadow on the ground.

"The skies are mediocre in western Michigan where I now observe from in the evenings. I pride myself in taking long-exposure astrophotographs of deep-sky objects and always try to maintain a natural look."

Right: The Cygnus Wall and North America Nebula (NGC 7000)

Celestron Cometron FirstScope 76

Designed with the beginner or casual astronomer in mind, this tabletop telescope is portable, provides good views and doesn't take up too much space

Telescope advice

Cost: £69.99 (approx. $91.42)
From: Argos
Type: Reflector
Aperture: 76mm (2.99")
Focal length: 300mm (12")

Best for...

- Beginners
- Small budgets
- Planetary viewing
- Lunar viewing
- Bright deep-sky objects

There are several things that novice sky-watchers crave when choosing their very first telescope: portability, ease of use and a price that's not going to break the bank. We're pleased to say that the Celestron Cometron FirstScope ticks all of the boxes on these fronts. What's more, this tabletop telescope comes with all of the accessories you need for any beginner wanting a fuss-free tour of the night sky, providing much improved and more comfortable views of the planets and lunar surface over the naked eye or even binoculars.

When unpacking the FirstScope, you'll notice that it is already preassembled, with only the 5x24 finderscope needing to be affixed to the telescope tube. The FirstScope is supplied with two Kellner eyepieces - a 10mm and a 20mm - and possesses a fast focal ratio to provide a wide field of view that's ideal for not just viewing the planets and the lunar surface, but also allows the user to view wide-angle star clusters, too.

Weighing in at a mere 1.95 kilograms, the FirstScope is ideal for those looking for a grab-and-go instrument. On close inspection of the overall build of this reflector, the finish isn't perfect, with traces of glue apparent on the tube. Considering what you get for the price, though, the scope's plastics aren't glossy and cheap. You'll notice that the telescope's base is short, meaning that you'll need to place it on a table for comfortable use. On the plus side, if you have children who have been pestering you for a telescope, the Cometron FirstScope is the perfect solution, especially given the low price and ease of use.

With Newtonian designs, the two mirrors within the tube should be aligned. Astronomers usually achieve this process - known as collimation - using thumbscrews to adjust the optical system. Unfortunately, these aids are only usually on more expensive models, meaning that it was quite a task trying to collimate the FirstScope, as the primary mirror isn't adjustable and a collimation cap or eyepiece isn't actually included with the telescope. Nevertheless, and given that we have been spoilt for clear skies throughout the end of 2020, we couldn't wait to tour the night sky - especially given how easy it is to get started in astronomy with this pint-sized scope.

Late November provided a gaggle of Solar System targets including Mars, Venus, Saturn and the Moon, to test the telescope's optical system. Our lunar companion was at 22 per cent illumination, meaning that there wasn't too much natural light pollution to hinder our views of the other targets we were keen to observe. With the eyepieces supplied, you won't get hugely close-up views of the surface of the Moon, but you'll be able to see craters and get a feel for the rugged terrain along the terminator. Views aren't hugely pin-sharp through the field of view, since the focuser tube is quite loose, but they are sure to delight those who have always wanted to get a closer look at the lunar surface without straining their eyes. With Venus in the west and shining at a stunning magnitude of -4.0, we turned the scope to the second planet from the Sun. As expected, we didn't see a great deal of detail, but

Left: The 5x24 finderscope should be replaced with a red-dot finder for easy navigation

> "VIEWS ARE SURE TO PROVIDE A WOW FACTOR FOR FIRST-TIME OBSERVERS"

Left: An alt-azimuth design is employed, allowing for simple use so that you can skip setting up and get observing

were treated to a white disc of the bright-white 'star'. Meanwhile, the Cometron's wide-angle views provided fair sights of the Pleiades star cluster, also known as Messier 45, in the constellation of Taurus. Each of the young, hot member stars in this open cluster were exquisite through the field of view. Using the finderscope did prove quite cumbersome during our observations though, making star-hopping quite difficult in light-polluted areas – for instance, it failed to pick up stars with magnitudes below naked-eye visibility – so it makes more sense to use a red dot finder for simpler navigation.

Jupiter, which shone at magnitude -2.1, rose in the south. While it was difficult to spot any details on the gas giant, such as its belts and Great Red Spot, the Galilean moons – Io, Ganymede, Europa and Callisto – appeared as bright spots either side of the king of the Solar System's limbs. While the views aren't as good as you'd expect through a more dedicated scope, they are sure to provide a wow factor for first-time observers.

If you're only looking for a piece of fuss-free equipment to compliment your existing telescope, we recommend a pair of binoculars. However, if you have children who have been bugging you for a telescope and you can't quite commit to a moderately priced instrument, then the Cometron FirstScope may be for you – especially if the lunar surface, the planets and casual glances at the night sky are of interest.

Right: It's not possible to collimate the FirstScope since the primary mirror is fixed

In the shops

The latest books, apps, software, tech and accessories for space and astronomy fans alike

Telescope

Meade Instruments StarPro 102

Cost: £174.89 / $239

From: B&H

The StarPro 102 is a classic telescope that's both simple to use and assemble. If you know someone who is happy to spend hours under the night sky, learning their way around without the aid of technology, then we fully recommend this well-built instrument.

This refractor makes use of an alt-azimuth mount as well as slow-motion cables for fine movements that allow the observer to accurately lock onto a target. Some mounts cause telescopes to jump from one positioning extreme to another, but we were pleased to discover that we could make incremental adjustments to the tube's orientation with ease.

It's supplied with a tripod, three eyepieces with focal lengths of 26mm, 9mm and 6.3mm – offering magnifications of 25x, 73x and 105x – plus a Barlow lens that can double the 'power' of an eyepiece. If you will be looking to share images of astronomical finds with friends or may want to try out basic astrophotography, a smartphone adapter is included.

Sky map

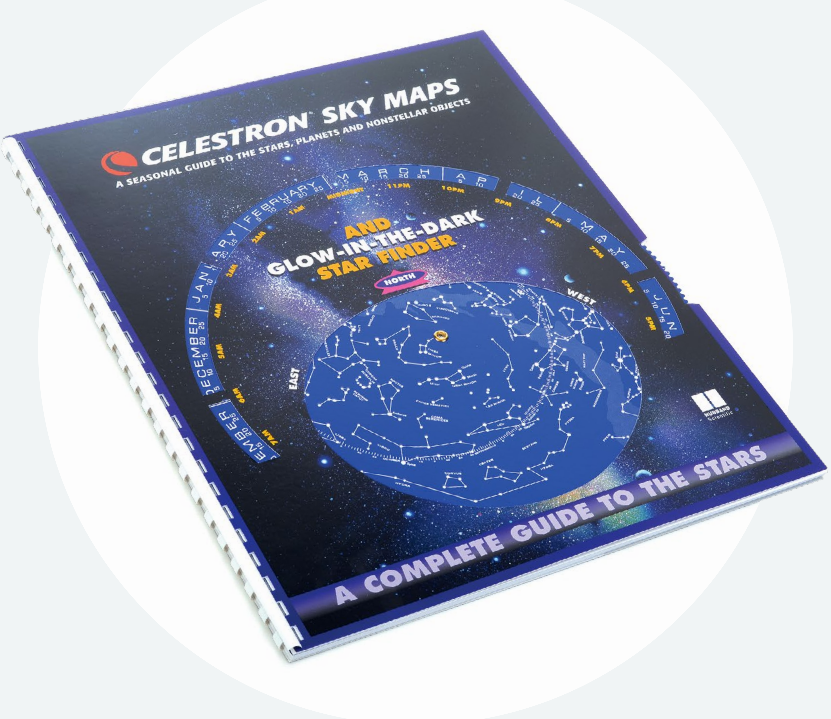
Celestron Sky Maps

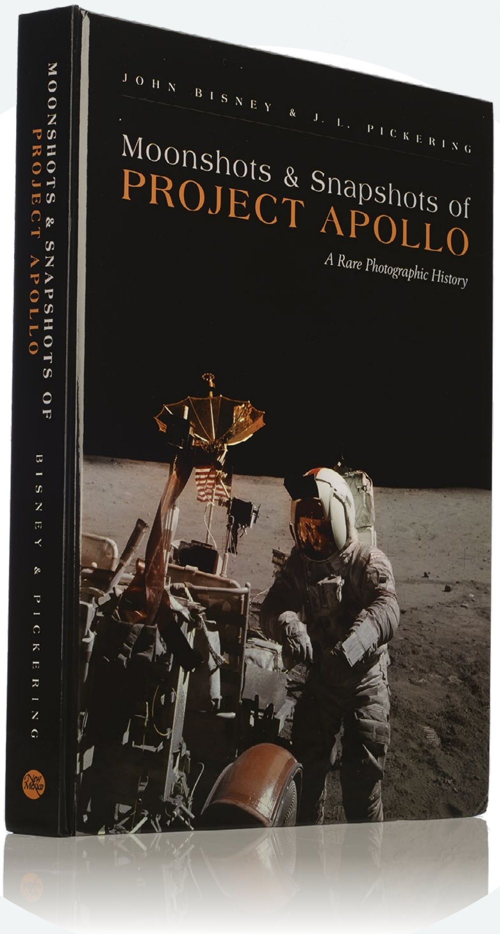
Cost: £30 / $30.87

From: Amazon

On a clear night there may be hundreds of sparkling stars above your head, so many that even the most familiar constellation patterns can become lost in the dazzling display. To help you find your way around the stars, Celestron's sky maps are the perfect accompaniment to your telescope. Think of them as an atlas to the night sky as seen in the Northern Hemisphere, with each spiral-bound page showing a different constellation alongside useful celestial information and details of bright targets for your telescope. The maps cover all four seasons, making this the perfect guide to the night sky whatever time of the year you are observing.

Celestron Sky Maps comes with a planisphere – a 'star finder' with a rotating map of the sky that can be turned to any date and time to show what will be visible in the night sky at that moment. And because the star patterns and names glow in the dark, it means you don't have to spoil your dark-adapted vision by using a torch to see the star finder's details. If you are new to the night sky and the constellations are unfamiliar to you, then *Celestron Sky Maps* are the perfect learning tool.


CELESTRON SKY MAPS
A SEASONAL GUIDE TO THE STARS, PLANETS AND NONSTELLAR OBJECTS
AND GLOW-IN-THE-DARK STAR FINDER
A COMPLETE GUIDE TO THE STARS


JOHN BISNEY & J. L. PICKERING
Moonshots & Snapshots of
PROJECT APOLLO
A Rare Photographic History
MOONSHOTS & SNAPSHOTS OF PROJECT APOLLO
BISNEY & PICKERING

Book

Moonshots and Snapshots of Project Apollo: A Rare Photographic History

Cost: £39.95 / $39.99
From: University of New Mexico Press
If you think this book by CNN space journalist John Bisney and manned spaceflight historian J. L. Pickering contains images that you have seen on the internet, then you would be mistaken. We were impressed to discover that the authors have done an excellent job of acquiring shots that haven't been released into the public domain.

It's not all pictures though; each of the chapters – which are dedicated in chronological order to the Apollo, Skylab and Apollo-Soyuz missions – contain concise, yet comprehensive text that focuses on the excellent selection of images, which all convey the enthusiasm and dedication to the Apollo program.

It's quite easy to glance at a picture and miss the finer details. However, the captions ensure that the reader doesn't miss a thing, as well as providing insights behind what is regarded as the golden age of US manned spaceflight. As we leafed through the pages, we received both a candid and formal view of the enthusiasm and dedication of the launch and flight crews, flight directors, engineers and astronauts, as well as their family members. An excellent hardback book for the space lover, *Moonshots and Snapshots of Project Apollo* is beautifully and passionately put together and is certainly a tome that will be picked up time and again.

CCD

Celestron NexImage Solar System Imager

Cost: £129 / $220
From: Celestron
When it comes to astrophotography, many find it daunting. However, the NexImage Solar System Imager is both easy to set up and use. It comes with a 'starter' CD that features easy-to-follow steps.

Accompanying the NexImage package is video capture software AMCap, plus Registax for image processing. Be sure to take extra care when saving new files – you can overwrite them quite easily and without warning! The 1.25" adapter was a bit on the small side and measured at about 1.23", so we had to ensure that the camera was fitted properly to the eyepiece holder. Additionally, the USB cable is attached to the imager, so you might not lose it in the dark, but if it gets damaged the camera becomes useless. When put to the test, the NexImage provided reasonable colour sensitivity, but it sadly seemed to produce quite a bit of noise and gives some objects a reddish hue.

Binoculars

Celestron Cometron 12x70

Cost: £108 (approx. $141.09)
From: Astroshop.eu
Testing these binoculars on terrestrial views, these 12x70s were surprisingly light to hold and use. But when it came to astronomical viewing, we quickly found that they were a bit on the heavy side for steady sights due to the 12x magnification, so we opted to mount them on a tripod. Turning the binoculars to a variety of targets, we quickly noticed their ability to make faint objects brighter: for instance, a satellite, dim to the naked eye while making its way across the night sky, seemed to obtain a significant magnitude thanks to dual 70mm aperture lenses that give the best light-gathering ability possible.

The Pleiades looked superb, with its stellar members effortlessly picked out with a pleasing view. Moving across the sky and to a waning crescent Moon before moving on to a very good view of the Andromeda Galaxy, unfortunately the Cometron's field of view did reveal some slight coma (field curvature) in the left optics, as well as a touch of colour fringing. Crisper views were found at the centre of the lenses, but the binoculars' eyepieces also fogged up when there was over 50 per cent humidity. Despite the few optical issues, we believe that these 12x70s are fair for the price - especially if you're looking for inexpensive, large-aperture binoculars with a high magnification that provide good views.

Accessories

Celestron 1.25" colour filters

Cost: £35 (approx. $45.73)
From: Celestron
If you're a keen observer of the night sky, filters are a must to enhance your views, and well-renowned manufacturer Celestron offers these accessories in their usual high quality. Easy to screw to the base of all eyepieces, provided they have a 1.25-inch fitting, we got stuck into observing the lunar surface along with Mars, Saturn and Jupiter.

Turning our telescope to the surface of the Moon, the yellow filter didn't disappoint, picking out the even finer details of craters as well as the belts and poles of gas giant Jupiter. Switching out for an orange filter, we were impressed with how Saturn's cloud bands improved our view of the ringed planet. We took advantage of the Red Planet's positioning in the evening sky and employed a red filter to pick out the Martian polar ice cap.

Celestron's coloured filters perform just as well as they are made - the black rims around the edge are superbly manufactured, while the embossed Wratten number and filter colour are easy to read under a red flashlight during an observing session.

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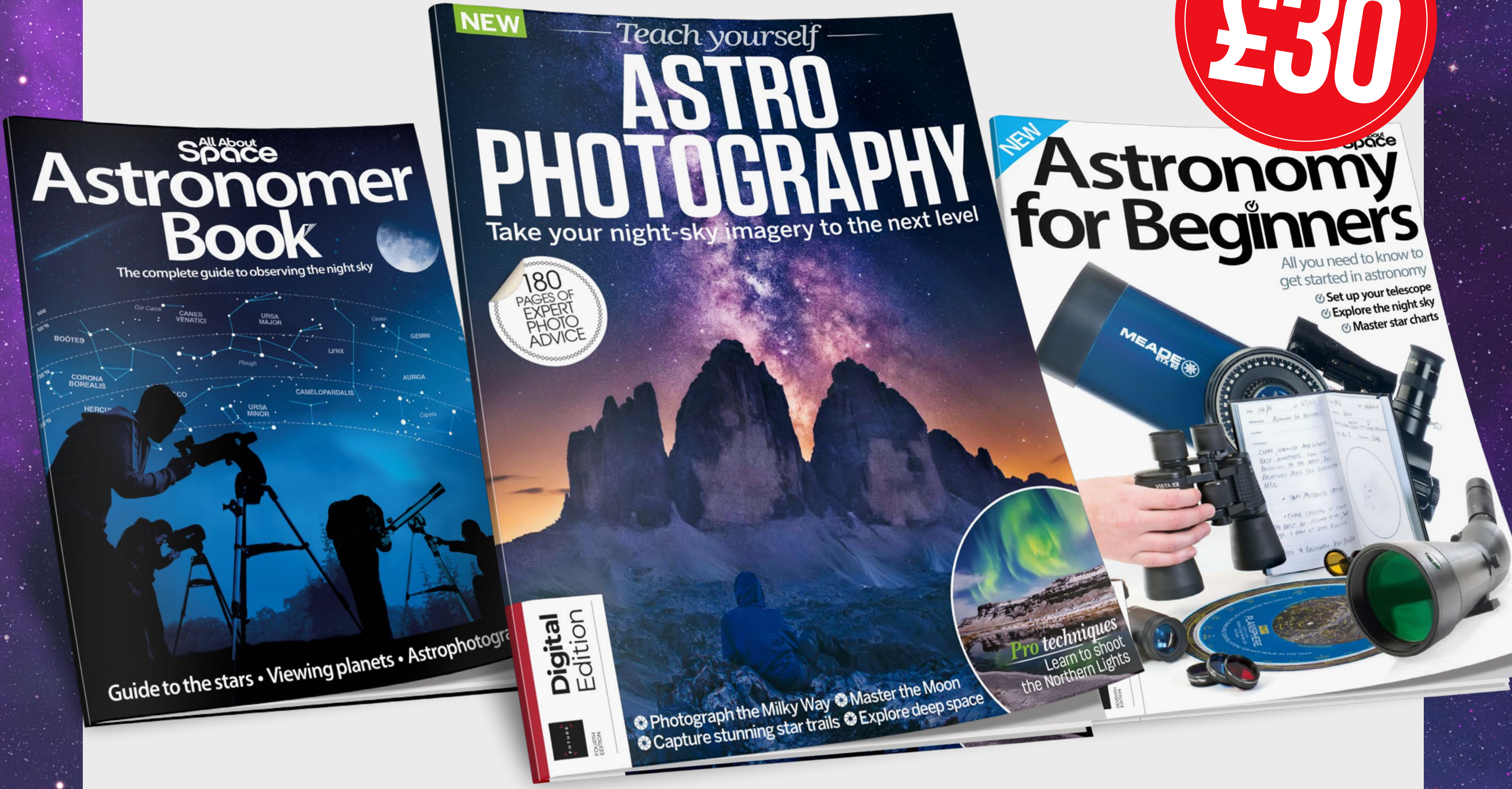
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Katie Bouman

Bouman was instrumental in imaging a black hole

Bouman's algorithm helped us to image the invisible

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In 2019 the Event Horizon Telescope (EHT) - a global array of radio telescopes working together as part of an international effort - captured an image of the black hole that resides in Messier 87, for the first time revealing what these galactic gobblers truly look like. Katie Bouman was one of the brilliant minds behind the scenes, contributing code to the algorithm that made processing the telescope data into an image a possibility.

Bouman grew up in West Lafayette, Indiana, and even as a high school student was conducting imaging research at the local Purdue University. It was in her final year of school in 2007 that she first learned about the EHT. After graduating from the University of Michigan in 2011, Bouman furthered her studies at the Massachusetts Institute of Technology (MIT), earning her master's and then doctorate in electrical engineering and computer science.

While completing her doctorate at MIT, Bouman joined the EHT imaging team. In 2016 she presented a TEDx talk about the project, called 'How to take a picture of a black hole'. In this talk she compared imaging a distant black hole to taking a picture of an orange on the Moon, explaining that because of the small scale and the laws of diffraction, the only telescope that could image a black hole would need to be the size of Earth.

While building a telescope of this size is impossible, linking existing telescopes and combining their data is something already done in astronomy. It was this idea that brought eight telescopes spanning four continents together to become the EHT. But while multiple sources give a wider picture, there are still gaps in the data - this is where Bouman's algorithm comes in.

Reconstructing an image from limited measurements means filling in a lot of blanks in sparse, noisy data. Because the possibilities are endless, an algorithm applies images of what we expect to see in our universe and fills in these gaps, composing the most likely result. However, Bouman didn't want to force what's expected by the theory of general relativity into the end result. As well as comparing the data to our impressions of black holes and images of other galactic objects, the algorithm also tried to fill in the gaps with unrelated everyday images to avoid bias. If all of these came out with the same result, this would confirm that a true image had been created from the data.

The development of Bouman's algorithm, Continuous High-resolution Image Reconstruction using Patch priors (CHIRP), involved a large team of researchers from MIT and the Harvard-Smithsonian Center for Astrophysics. Once the code was complete, the algorithm was applied to data taken by the EHT network in 2017 over several weeks. The amount of data was staggering, amassing five petabytes. After much time correlating data, sifting through noise and calibrating information, the end result was the iconic black hole image: an orange ring of glowing matter surrounding a disc of darkness.

Although the media focused much of its attention on Bouman - essentially making her the face of the discovery - she highlighted that the scientific success came from the collective efforts of the people involved: "No one algorithm or person made this image. It required the amazing talent of a team of scientists from around the globe and years of hard work to develop the instrument, data processing, imaging methods and analysis techniques that were necessary to pull off this seemingly impossible feat."

Now an assistant professor at the California Institute of Technology, Bouman plans to work on new systems and techniques for computational imaging. The next steps in black hole imaging are to attempt to capture the black hole at the centre of our own galaxy, and to capture footage of a black hole for scientific study.

All About Space

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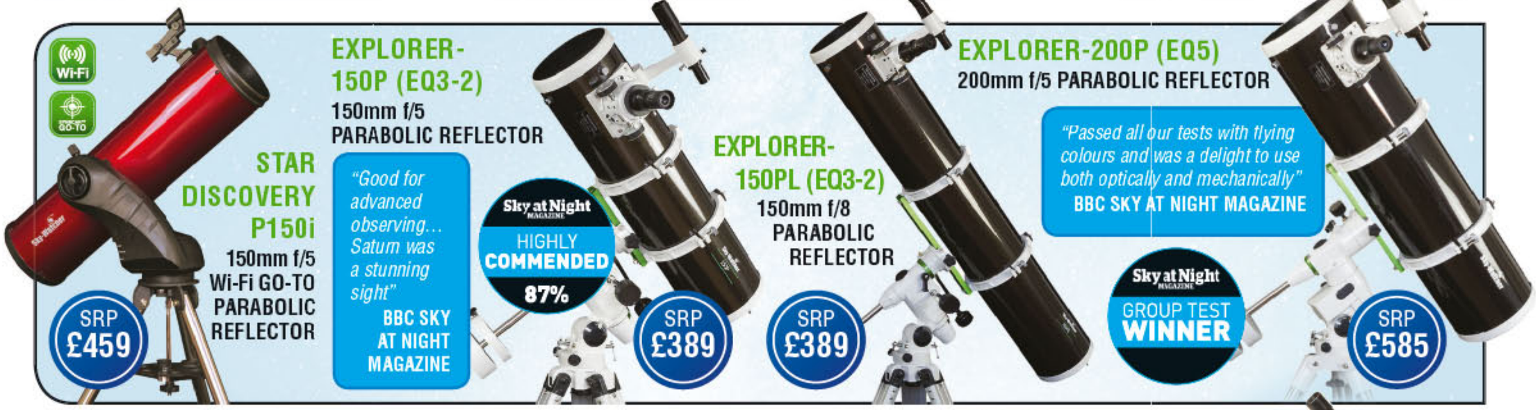

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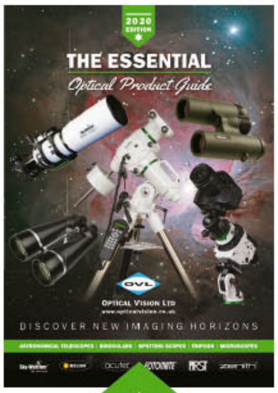

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